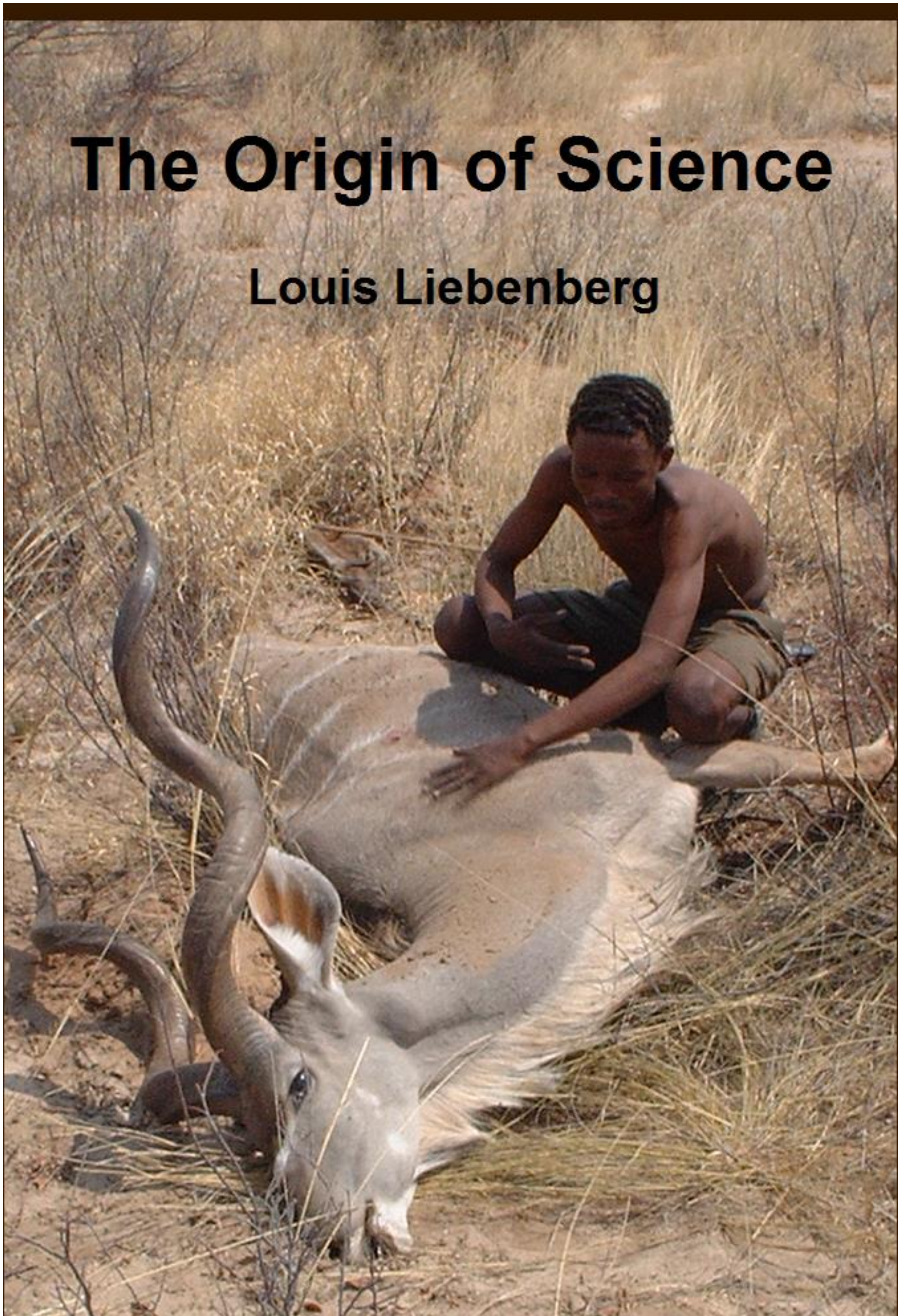
The Origin of Science

Louis Liebenberg



"This is an extraordinary book... a major insight into the nature and origins of scientific thinking." **Steven Pinker**

The Origin of Science

The Evolutionary Roots of Scientific Reasoning and its Implications for Citizen Science

Louis Liebenberg

CyberTracker

Cape Town, South Africa
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Endorsements

“This is an extraordinary book. Louis Liebenberg, our intrepid and erudite guide, gives us a fascinating view of a people and a way of life that have much to say about who we are, but which soon will vanish forever. His data are precious, his stories are gripping, and his theory is a major insight into the nature and origins of scientific thinking, and thus of what makes us unique as a species.” **Steven Pinker**, Harvard College Professor of Psychology, Harvard University, and author of *How the Mind Works.*

“Louis Liebenberg’s argument about the evolution of scientific thinking is highly original and deeply important.” **Daniel E. Lieberman**, Professor of Human Evolutionary Biology at Harvard University.

“Although many theories of human brain evolution have been offered over the years, Louis Liebenberg’s is refreshingly straightforward.” *PsycCRITIQUES.*

“*The Origin of Science* is a stunningly wide-ranging, original, and important book.” **Peter Carruthers**, Professor of Philosophy, University of Maryland, and author of *The Architecture of the Mind*.

“Charles Darwin and Louis Liebenberg have a lot in common. Their early research was supported financially by their parents, and both studied origins... Both risked their lives for their work.” **Ian Percival**, Professor of Physics and Astronomy at the University of Sussex and Queen Mary, University of London and the Dirac medal for theoretical physics.

“Louis Liebenberg is a scholar and adventurer whose work combines academic rigor, inspired leaps of insight, and a remarkable willingness to risk himself in pursuit of an idea.” **Christopher McDougall**, author of *Born to Run*.

Louis Liebenberg is an Associate of Human Evolutionary Biology at Harvard University and a Laureate of the Rolex Awards for Enterprise.

A New Vision of Science

In this book I will address one of the great mysteries of human evolution: How did the human mind evolve the ability to develop science?

The art of tracking may well be the origin of science. Science may have evolved more than a hundred thousand years ago with the evolution of modern hunter-gatherers. Scientific reasoning may therefore be an innate ability of the human mind. This may have far-reaching implications for self-education and citizen science.

The implication of this theory is that anyone, regardless of their level of education, whether or not they can read or write, regardless of their cultural background, can make a contribution to science. Kalahari trackers have been employed in modern scientific research using GPS-enabled handheld computers and have co-authored scientific papers. Citizen scientists have made fundamental contributions to science. From a simple observation of a bird captured on a smart phone through to a potential Einstein, some may be better than others, but everyone can participate in science.

Today humanity is becoming increasingly dependent on science and technology for survival, from our dependence on information technology through to solving problems related to energy production, food production, health, climate change and biodiversity conservation. Involving citizens in science may be crucial for the survival of humanity over the next hundred years.

Scientific reasoning was part of hunter-gatherer culture, along with music, storytelling and other aspects of their culture. Science and art should be an integral part of human culture, as it has been for more than a hundred thousand years.

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Chapter 5: The Art of Tracking

In this chapter I look at the art of tracking as practiced by Kalahari trackers in a traditional hunting context.

Chapter 6: The Evolution of Tracking

To reconstruct how tracking may have evolved, this chapter breaks down tracking into three levels. Climate change resulting in environmental change would have resulted in the evolution of tracking from simple to systematic through to speculative tracking. This would explain how, through natural selection, humans evolved the ability to develop creative science.

Chapter 7: The Evolution of Science

In this chapter I will develop a model of the growth of science based on an evolutionary definition of science. This model will allow us to resolve apparent paradoxes and explain how science evolved through natural selection.

Chapter 8: The Scientific Imagination

To develop an explanation of how science evolved, we need to have some understanding of what we mean by the term "science." In this book I will make a clear distinction between "empirical knowledge" and "creative science." I will look at how some scientists think when they engage in scientific reasoning and the views of various scientists and philosophers of science. I will point out the similarities between the art of tracking and modern science, with particular reference to modern physics.

Chapter 9: Science, Language and Art

Science required complex language and art played an important role in science. Science, language and art would therefore have co-evolved. Archaeological evidence for art may therefore be indirect evidence of science and language.

Chapter 10: Modern Tracking

If the art of tracking is the origin of science and a non-literate Kalahari tracker hunting with a bow-and-arrow uses scientific reasoning, then there is no reason why traditional trackers should not be employed in modern scientific research. The examples in this chapter break down barriers between conventional notions of "science" and "indigenous knowledge" and between literate and pre-literate cultures.

Chapter 11: Citizen Science

Scientific reasoning may well be an innate ability of the human mind. The implication of this hypothesis is that anyone can make a contribution to science. Regardless of their level of education, whether or not they can read or write, regardless of their cultural background… from a simple observation of a bird through to a potential Einstein, some may be better than others, but everyone can participate in science.

Chapter 12: The Future

To solve problems we face over the next fifty years, young scientists need to pursue their passion for science regardless of whether or not they have access to funding and resources. The burgeoning growth of self-education and citizen science may have far-reaching consequences for the future of scientific innovation. However, our passion for science needs to be tempered by ethics and compassion.

1

A Paradox of Human Evolution

As a young student, when I studied physics and applied mathematics, I noticed that the first three papers that Einstein published in 1905 had one thing in common: Each paper resolved an apparent paradox in physics. His paper on Special Relativity resolved the apparent paradox of relative motion of bodies with mass and the fact that the speed of light is constant. His paper on the photoelectric effect resolved the wave-particle paradox of electromagnetic radiation. His paper on Brownian motion explained why tiny particles immersed in a liquid move around randomly. Perhaps the most important lesson I learnt in physics is that if you want to do interesting research you need to look for an apparent paradox in science and then try to resolve it.

For Einstein, the fundamental motivation behind each paper, which would become his chief preoccupation in science for the rest of his life, was: "To recognize the unity of a complex of appearances which… seem to be separate things" (Holton, 1986). The hallmark of Einstein's most famous contributions was that he could deal with, use, illuminate, transform the existence of apparent contradictories or opposites, sometimes in concepts that had not yet been widely perceived to have polar character (Holton, 1973).

Thomas Kuhn (1963) points out that the history of science suggests that when a theory confronts an anomaly or a paradox, the resolution will be a new paradigm that transcends what went before.

In this book I will address a paradox in human evolution: How did the human mind evolve the ability to do scientific reasoning if it was assumed that scientific reasoning was not required for hunter-gather subsistence? Since the time of Alfred Wallace this apparent paradox have been reformulated a number of times.

This paradox led Alfred Wallace to conclude that the human brain could not be the product of natural selection. Wallace was one of the few nonracists of the nineteenth century. But like most of his contemporaries, he did not doubt the evident superiority of European ways. Hence, Wallace's dilemma: all "savages," from our actual ancestors to modern survivors, had brains fully capable of developing and appreciating all the finest subtleties of European art, morality and philosophy; yet they used (he believed), in the state of nature, only the tiniest fraction of that capacity in constructing their (apparently) rudimentary cultures… But natural selection can only fashion a feature for immediate use. The brain is vastly over designed for what it accomplished in primitive society; therefore Wallace argued that natural selection could not have built it:

"A brain one-half larger than that of the gorilla would … fully have sufficed for the limited mental development of the savage; and we must therefore admit that the large brain he actually possesses could never have been solely developed by any of those laws of evolution, whose essence is, that they lead to a degree of organization exactly proportionate to the wants of each species, never beyond those wants … Natural selection could only have endowed savage man with a brain a few degrees superior to that of an ape, whereas he actually possesses one very little inferior to that of a philosopher." (Wallace, 1870)

If our higher capacities arose before we used or needed them, then they cannot be the product of natural selection. And, if they originated in anticipation of a future need, then they must be the direct creation of a higher intelligence: "The inference I would draw from this class of phenomena is, that a superior intelligence has guided the development of man in a definite direction, and for a special purpose" (Wallace, 1870). In

Walace's view, the human brain could not be the product of natural selection, since it always possessed capacities so far in excess of its original function.

It has long been assumed not only that rational science originated with the Greek philosophic schools, but that the belief systems of prehistoric hunter-gatherers were dominated by superstitions and irrational beliefs. Hunter-gatherers were believed to have acted on the basis of exceedingly limited information, much of that information being wrong (see, for example, Popper, 1963; Washburn, 1978).

In 1978 Sherwood Washburn reformulated this apparent paradox. The brain evolved both in size and in neurological complexity over some millions of years. A fully modern brain had evolved at a time when all humans were hunter-gatherers. Yet the same brain that has been adapted for the needs of hunter-gatherer subsistence, today deals with the subtleties of modern mathematics and physics (Washburn, 1978).

Steven Pinker (1997) maintains that Wallace's paradox, the apparent evolutionary uselessness of human intelligence, is a central problem of psychology, biology, and the scientific worldview. Edward O. Wilson (1998) regards it as "the great mystery of human evolution: how to account for calculus and Mozart."

Wallace's paradox is more than just of academic interest – it has very real political implications.

In *Our Choice, A Plan to Solve the Climate Crisis*, Al Gore maintains that "our capacity to respond quickly when our survival is at stake is often limited to the kinds of threats our ancestors survived: snakes, fires, attacks by other humans, and other tangible dangers in the here and now. Global warming does not trigger those kinds of automatic responses… As a result, the automatic and semiautomatic brain responses that have ensured our survival over the millennia are uniquely unsuited to the role of motivating new behaviors and patterns necessary to solve the climate crisis" (Gore, 2009, pp 303-304).

James Lovelock in *The Vanishing Face of Gaia, A Final Warning* (2009: pp 13 and 52-53), maintains that "Of course, advances in science and technology emerged in Europe in the Middle Ages"… and quoting a column by Michael Shermer in *Scientific American* of August 2008, goes on to explain "why thinking anecdotally comes naturally but thinking scientifically does not… superstition and belief in magic are millions of years old, whereas science… is only a few hundred years old." Lovelock then goes on to despair that humans do not have the intellectual capacity to solve scientific problems in time to avert catastrophic climate change.

In the paper "Can a collapse of global civilization be avoided?" published in *The Proceedings of the Royal Society*, Paul and Anne Ehrlich (2013) claim that: "Until very recently, our ancestors had no reason to respond genetically or culturally to long-term issues… The forces of genetic and cultural selection were not creating brains or institutions capable of looking generations ahead; there would have been no selection pressures in that direction. Indeed, quite the opposite, selection probably favoured mechanisms to keep perception of the environmental background steady so that rapid changes (e.g. leopard approaching) would be obvious."

As far as written records are concerned, the critical or rationalist tradition of science can be traced back to the early Greek philosophic schools. Characteristic features of the scientific attitude are freedom of thought, critical debate and rational discussion. Thales, the founder of the Ionian school, seems to have created the tradition that one ought to tolerate criticism. Historically, the Ionian school was the first in which pupils criticized their masters, in one generation after the other (Popper, 1963).

Recently scholars have traced the historical origins of aspects of science to the ancient Mesopotamian civilizations about four thousand years ago (Fara, 2009).

The apparent paradox may be resolved if it is assumed that at least some of the first fully modern* hunter-gatherers were capable of scientific reasoning, and that the intellectual requirements of modern* science were, at least among the most intelligent members of hunter-gatherer bands, a necessity for the survival of modern hunter-gatherer societies.

The first creative science, practiced by possibly some of the earliest members of *Homo sapiens* who had modern* intellects, may have been the art of tracking. The art of tracking is a science that requires fundamentally the same intellectual abilities as modern* physics (see Chapter 8). Since mathematics, which may be regarded as quasi-empirical, involves essentially the same intellectual processes as science (Lakatos, 1978b), the intellectual requirements of tracking are therefore also those that are required for mathematics.

It is interesting to note that Carl Sagan (1996) independently came to the conclusion that: "For me, all of these formidable forensic tracking skills are science in action" (*The Demon-Haunted World*, Chapter 18). He was unaware of my first book *The Art of Tracking: The Origin of Science* (1990), which had a very limited distribution.

We will first look at the art of tracking within the context of hunting and gathering, with particular reference to persistence hunting. We will then develop a theory on the evolution of tracking and the evolution of science, with reference to philosophy of science. The similarities between tracking and modern science will show that the art of tracking is a science and therefore may be the origin of science. Lastly, we look at the implications of this theory for modern tracking, citizen science and self-education in the future.

*FOOTNOTE: With “modern hunter-gatherers” and “modern intellects,” the term “modern” is used in the archaeological sense of the word. With “modern science” and “modern physics” the term “modern” refers to science and physics practiced during and since the twentieth century.

2

The Kudu Chase

Lone Tree, Central Kalahari, August 29, 1990.

We had been hunting for two weeks with no luck. It was at the end of the dry season and the dry grass made it difficult to stalk close enough to animals to get a good shot with a bow and arrow. That morning we were tracking a healthy kudu bull. By midday we caught up with it, but again it ran away. This was when !Nate, Kayate and Boroh//xao decided to run it down. It was an extremely hot day and conditions were ideal for persistence hunting. !Nam!kabe, who was too old to run far, went back to our camp with all our unnecessary weight – bows and arrows, digging sticks, clubs and my camera equipment. They told me to go back with !Nam!kabe, because no white man can run down a kudu in such heat. But I insisted that I had to run with them so that I can see how they do it.

So we drank our fill, emptying the water bottles before setting off at a stiff pace. Even at the outset my boots felt heavy and I found it difficult to keep up the pace in the sandy terrain. At times they would run away from me, but when they lost the spoor and were delayed in looking for the spoor I managed to catch up with them. At times they would fan out, each hunter making a prediction of where he thought the kudu was heading, so that if the kudu followed a curved path, one of them would gain an advantage by taking a short cut. The others would then cut back to catch up with the one who picked up the spoor.

Boroh//xao was the first to drop out and start walking. I managed to keep up with !Nate while Kayate had increased his pace and was pulling away from us. When we got to some thick bush, however, I lost sight of !Nate who was about a hundred *meters ahead of me. The terrain was difficult in places and several times I lost the trail. In the process Boroh//xao had caught up with me again, and since I was quite exhausted by that time, decided to follow the trail with him at a fast walking pace.*

As we followed the tracks I could visualise the whole event unfolding in front of me. The kudu started to show signs of hyperthermia. It was kicking up sand and its stride was getting shorter. As it ran from shade to shade, the distances between its resting periods became shorter and shorter. In visualising the kudu I projected myself into its situation. Concentrating on the spoor I was so caught up in the event that I was completely unaware of my own state of exhaustion. As if in an almost trance-like state I could not only see how the kudu was leaping from one set of tracks to the next, but in my body I could actually feel how the kudu was moving. In a sense it felt as if I myself actually became the kudu, as if I myself was leaping from one set of tracks to the next.

Every time Kayate and !Nate caught up with it, it would run away, leaving them behind. But while it accelerated from its resting position and stop to rest again, the hunters were running at a constant pace. The distinctively human sweating apparatus and relative hairlessness give the hunters an advantage by keeping their bodies cool in the midday heat. But in the process they risk becoming dehydrated. The hunters therefore have to know their bodies and measure their own condition against that of the kudu. If they run too fast, they will exhaust themselves or overheat, but if they do not run fast enough, they will never exhaust or overheat the kudu. They must run fast enough not to allow the kudu too much time to rest, which is when the kudu cools down, restoring core body temperature.

We could see from the spoor that Kayate had dropped out and that only !Nate was chasing it. Boroh//xao pointed to the moon and said that the kudu will get away, because the moon was out in daylight. But by this time the kudu seemed to be so exhausted that I insisted that we should carry on. At one point a cold shiver went through my whole body and for the first time I realised that I was dragging my feet in the sand. Some times my legs buckled under me and I would stumble over branches, but through intense concentration on the spoor it was as if though my mind was simply dragging my body along.

!Nate had picked up his pace and was closing in on the kudu. With the kudu showing signs of severe exhaustion or overheating, !Nate broke into a sprint, running in front of the kudu and keeping it from getting into the shade. At the same time he tried to cut in front of it to chase it back to Kayate.

When we finally caught up with !Nate and Kayate, they were on their way back to the camp. When I asked !Nate where the kudu was, he told me that it got away. When he saw the disappointment on my face he laughed at me, telling me that the kudu was not very far. I asked if I could drink the stomach water of the kudu to quench my thirst. I had drunk the stomach water of gemsbok on a previous hunt, and although it tasted like rotting grass soup, it was not too bad. At this stage I was so thirsty that taste was not much of a concern. But !Nate said that I would die if I drank it, because the kudu was feeding on a leaf that is poisonous to humans.

As we started to walk back to our camp, my mind relaxed and I was suddenly overcome by a sense of total exhaustion. My legs were weak and shaky and my mouth was dry. I asked !Nate if there were any succulent roots I could dig up, but he replied that it did not rain in that part of the Kalahari for a long time and that there were no water.

Half way back to the camp I realised that my armpits were bone dry. I had stopped sweating - the first symptoms of heat stroke. As the implications of my situation dawned upon me, I experienced an overwhelming sinking sensation - as if the vast dry Kalahari was like an endless ocean and I was sinking down deeper and deeper.

I found myself in a desperate situation. I had to get into the shade to cool down my body, but at the same time I had to get water as soon as possible. If I dehydrated any further and my body overheated because I no longer produced sweat to cool down, I could die very rapidly. !Nate, who had been watching me closely, realised that I was in serious trouble. He told me that he will run back to our camp and ask !Nam!kabe to bring me water.

After resting in the shade for a while, Kayate urged me to walk further, because the camp was still very far and the sun was going down. Once it got dark, !Nam!kabe will not be able to follow !Nate's tracks back to find us. Walking very slowly, I *experienced the ultimate sense of helplessness. My life depended totally on !Nate. If I tried to walk too fast I could kill myself, yet I had to try and make as much progress as possible because if I did not get water soon I could also die. Every now and then I would rest in the shade, and after a while Kayate would urge me on again.*

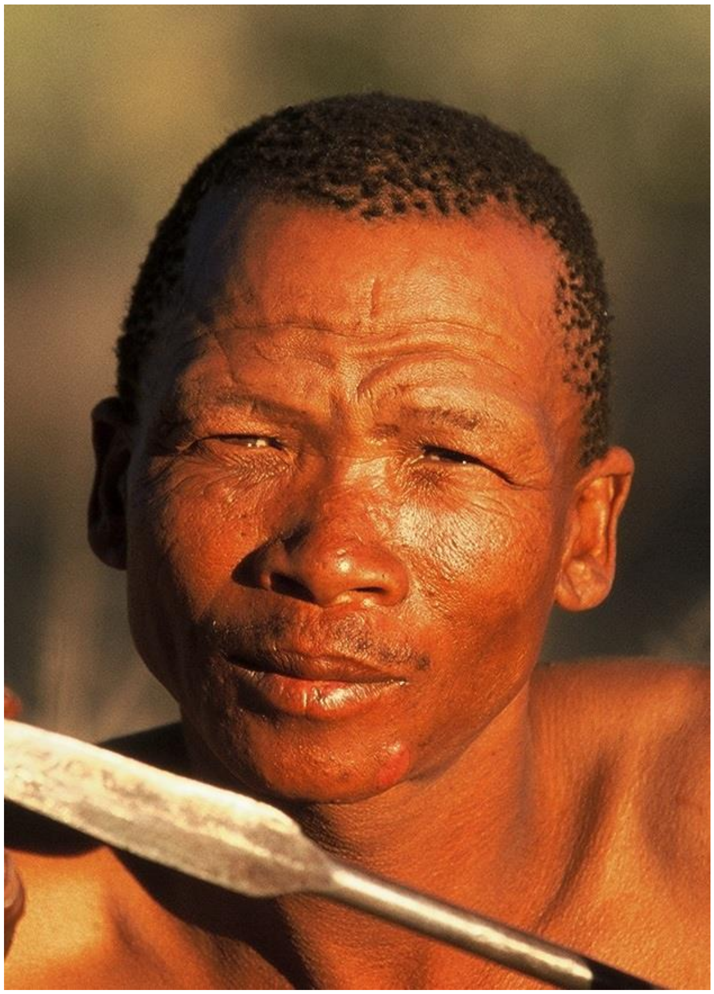


Fig. 1: !Nate of Lone Tree, Central Kalahari, Botswana (Photo: Rolex/Eric Vandeville)

After what seemed to be an eternity the sight of !Nam!kabe carrying several water bottles created an incredible sense of relief. But I still had a long way to go. !Nam!kabe explained that I must not drink a lot of water, because if I drank too much water too quickly I could die. I first had to wash my face and wet my hair to cool down my head. When you suffer from heat stroke you will die if your brain overheats. Only after cooling my head could I take small sips of water, slowly taking in water over an extended period of time.

Later !Nate told me that he also stopped sweating by the time he reached the camp. When he chased the kudu, after everyone else had dropped out, his timing was so fine that had he chased the kudu just a short distance further, he could have killed himself. He risked his own life to save my life.

It took a while for the significance of this single event to sink in. Apart from the fact that I almost lost my life in the process, my spontaneous spur-of-the-moment decision to run with them resulted in something quite unique. For more than fifty years, the Kalahari hunter-gatherers were amongst the most intensively studied population group. Yet, as far as we know, not a single anthropologist had witnessed the persistence hunt. There have been several anecdotal accounts of persistence hunting, but no one (apart from the hunters themselves) had actually witnessed it.

One reason may be that, unlike the bow-and-arrow which draws attention to itself, the persistence hunt requires no weapons. There is therefore no specific weapon or artifact that would prompt an anthropologist to ask hunters about it – and no direct evidence of it in the archaeological record. Unless you already knew about it, it would not occur to you that you should ask hunters about it. /Ui /Ukxa of //Auru village was a young hunter when the Marshall family first arrived in the 1950's at Nyae Nyae in Namibia. I asked him if anybody have ever asked him about the persistence hunt. He replied: "No, people only asked me about the bow and arrow." Since nobody asked them, hunters simply never told anthropologists about it.

Persistence hunting was probably one of the first forms of human hunting, yet a tradition that lasted perhaps as long as two million years was only witnessed in the very last decade before it died out. In this book I will show that persistence hunting may have played a critical role in the origin of science.

In 2001 I worked with the BBC to film Karoha Langwane running the persistence hunt for *The Life of Mammals,* presented by David Attenborough. A video link can be found on www.cybertracker.org to the BBC video of the persistence hunt.

Link to video: http://cybertracker.org/persistence-hunting-attenborough

3

Hunter-Gatherer Subsistence

To reconstruct the context in which hunting and the art of tracking may have evolved, it is useful to identify and define various aspects of hunter-gatherer subsistence. While the methods used by recent hunter-gatherers cannot simply be retrojected back into the past an analysis of known methods of hunting and gathering may help to recreate the ways in which hominin subsistence may have evolved.

Human evolution cannot be treated in isolation from the environment. The environment is not a static background, but an interacting agent, and humans should be seen as a part of the biological community. A full understanding of human evolution would require a study of community evolution as the product of ecological interactions (Foley, 1984a). Nevertheless, the evolution of hunting and gathering would have played a principle part in hominin evolution. And since the art of tracking is one of the most fundamental and universal factors in hunting, the evolution of tracking would have played an important role in the development of hunting.

Foraging

Foraging is the searching for and collecting of plant foods. The last common ancestor of apes and hominin was probably a mixed knuckle walker and tree climber. The first hominins, however, appear to have been bipeds of some sort (Richmond and Jungers, 2008; Lovejoy et al., 2009). Bipedalism may have been favored because it is more economical for walking than knucle-walking (Sockol et al., 2007).

Although there is no evidence that australopiths ever made stone tools, items such as leaves, stems, wood and stones must have been modified into simple tools in much the same way as seen among chimpanzees. Stone hammers, for example, can be used to crack hard fruits or nuts. Various nature facts have been employed by recent hunter-gatherers, among them sticks, stones, pebbles, shells, thorns, leaves, twigs, bones, porcupine quills and teeth, which would not be recognized as tools in the archaeological record (Oswalt, 1976).

One of the most important tools used by foragers is the simple digging stick. Since it was first deliberately sharpened, probably millions of years ago, the digging stick has probably remained unchanged until the present. It is more likely than not that australopiths used digging sticks to dig up roots and such tools have been used ever since (including today).

Foraging also involves the searching for transporting of plant foods to a home base or midday-rest location, to be processed and shared with other members of the band. Although it is not known whether some of the australopiths (who were diverse and varied) were co-operative gatherers, it is possible that a shift from individual foraging to co-operative gathering, together with increased meat consumption, may perhaps have represented a significant adaptation with the appearance of early *Homo* some 2.5 million years ago. At a later stage fire would have been used for cooking. Apart from food-sharing, information about plant and animal life would also be shared. Hunter-gatherers also gathered a wide range of plant foods whose digestion was facilitated by grinding, crushing, soaking, cooking or other means of food processing (Wrangham, 2009).

Cooperation and sharing information may save a considerable amount of energy in the food quest (Tomasello, 2009). Communication would have allowed a much greater knowledge of plant communities, and sharing knowledge of the terrain would have narrowed down the search for plant foods. Men could also have informed women of the location of plant foods, while women could have informed men about localities of possible sources of meat.

Scavenging

Scavenging involves obtaining of meat from carcasses of animals killed by other species, or of animals that died of non-predatory causes. It has been observed in non-human primates such as chimpanzees, baboons and orangutans. These observations support the idea that early hominins may have scavenged (Hasegawa et al., 1983). It is unlikely that early foraging hominins were engaged in anything more than casual scavenging to supplement a diet consisting mainly of plant foods.

Carcasses are comparatively rare, largely because of hyenas, which are impressively efficient at finding kills. According to Cooper (1991), hyenas in Kruger Park typically arrive at lion kill sites within 30 minutes of a kill, even at night. Given that a large percentage of kills occur at night, it is probable that only a fraction of kills, notably those made during the day, were available for scavenging by diurnal hominids (Lieberman et al. 2009).

In contrast to casual scavenging, systematic scavenging may be defined as the active search for carcasses. Watching for circling vultures to determine the locality of carcasses, hominins could significantly increase their access to meat. While the sight of circling vultures is an obvious sign of a carcass, Kalahari hunter-gathers also watch the flight patterns of vultures. When several vultures are seen to be heading in a specific direction, this may indicate the presence of a carcass in the distance, even when it is too far to actually see the circling vultures.

The evolution of endurance running abilities would have increased the meat yield of scavenging (Bramble and Lieberman, 2004). The ability to drive off other scavengers, such as jackals and hyaenas, would not only have given hominins access to a larger number of carcasses, but also to greater portions of the carcasses.

Meat robbing (or "competition" or "power" scavenging) may be defined as appropriation of the fresh kills of dangerous predators by means of weapons, fire or bluffing. From using weapons for self-defence against predators, some hominins may have developed the ability to use them to drive off scavengers and predators from fresh kills. Stones may have been thrown as missiles, and clubs and spears wielded to ward off attacks. Though some smaller and more timid scavengers and predators (such as single or small numbers of jackals, hyaenas, cheetahs or wild dogs) may have been driven off in this way, it is unlikely that hominins would have been able to chase away large predators such as lions, by physically attacking them.

The most likely source of scavenged carcasses would have been lion kills, because lions, unlike hyenas, do not consume all their prey, but instead leave behind marrow, brains and sometimes flesh (Blumenschine, 1987, 1988). Leopard and sabertooth kills are additional possible sources of edible animal tissue (Cavallo and Blumenschine, 1989; Marean, 1989), but it is unclear how common such carcasses would have been, and how much of the carcass sabertooths would have consumed (Van Valkenburgh, 2001).

Fire, which may initially have provided protection against predators, may also have been used more aggressively. By hurling glowing pieces of wood or setting fire to the grass, as recent hunter-gatherers of the Kalahari have been observed to do (Steyn, 1984a), even lions may be driven off.

Finally, bluffing would have increased the effectiveness of meat robbing, not only in reducing the risk of injury by avoiding physical contact, but also in enabling hominins to drive off predators that were too dangerous to confront directly. Bluffing dangerous predators to drive them from their kills is a bold aggressive act that requires knowledge of how different predators react under specific conditions.

Their size and sociality make lions the most formidable predators for hominins to deal with, yet recent hunter-gatherers' use of bluffing to appropriate lion kills suggest that hominin scavengers may have done the same. When Kalahari hunters observe a large number of circling vultures, they run to the point and drive off the predators. When hunters find a pride of lions at the carcass, they first study them carefully to determine how hungry they are. If the lions have just started eating, they will not be easily driven off. On the other hand, if they are full and lazy, they may be reluctant to move. Choosing the right psychological moment, the hunters rush at them, shouting and waving their arms to drive the lions off the kill (Silberbauer, 1965; Lee, 1979). Grass fires may also be used to drive the predators off (Silberbauer, 1965; Tanaka, 1980; Steyn, 1984a).

The Hadza have also been observed to use scavenging in which groups drive off lions or hyenas from a kill using weapons (O'Connell et al., 1988; Potts, 1988; Bunn and Ezzo, 1993). According to O'Connell and colleagues (1988), 85% of the carcass weight that the Hadza scavenged was acquired by driving off or killing the initial predator (mostly lions).

Scavenging may have been an important and distinct adaptation in hominin evolution. At a time when hominins were only capable of occasionally killing and defending their own prey, they may have relied mostly on scavenging to obtain meat, skin and other substances from carcasses. The development of scavenging involved significant cultural adaptations. While it may have been an important adaptation in its own right, in the sense that scavenging constituted the most reliable method of meat acquisition during a major period of hominin evolution, it may have been instrumental in making possible the transition from predation to hunting.

Hunting

Chimpanzees have been observed to prey on small animals and the young of middle-sized mammals (Stanford, 1999). Chimpanzees, for example, have been known to follow their prey stealthily for a long period, sometimes for more than an hour, in order to sneak up on it. Two or more chimpanzees may co-operate in stalking their prey, arranging themselves spatially in such a way that it cannot escape (Tanaka, 1980). However, running is rare among chimpanzees, comprising less than 1% of their locomotor repertoire (Hunt, 1991). Moreover, when chimpanzees run during hunting or chasing, they typically sprint rapidly for about 100 m, fatigue quickly, and then pant heavily while resting to cool down (R. Wrangham, as quoted in Lieberman et al, 2009).

In all probability, stones, throwing clubs or even the first crude spears would not have been effective enough as missiles to bring down large animals at, or even near, the place where they were attacked. When hominins became bipedal they would have lost some speed, becoming less able to catch prey with short, fast charges. They would, however, have gained endurance and become better adapted for persistence hunting. Endurance running is a derived capability of the genus *Homo* and may have played a key role in the evolution of the human body form (Bramble and Lieberman, 2004).

Persistence Hunting

Persistence hunting may have been the origin of hunting and represent a transition from predation to hunting. Early forms of persistence hunting that involved simple and systematic tracking would have been a form of predation, while more sophisticated forms persistence hunting that involves speculative tracking would have been the first form of hunting that involves creative human culture.

Persistence hunting takes place during the hottest time of the day and involves chasing an animal until it is run down.

It is unlikely that early *Homo* would have been able to develop persistence hunting unless it already had well-developed endurance running abilities as well as tracking skills. As Bramble and Lieberman (2004), suggest, it is very likely that endurance running was first practiced in the context of scavenging.

If hominins used endurance running to increase the yield from scavenging, then there would have been strong selective pressure to increase the speed, distance, heat loss, economy and other capabilities that are part of endurance running, and once they had achieved high-speed endurance running they would have had the potential to develop persistence hunting. Endurance running for increasingly competitive scavenging may have preadapted *Homo* for persistence hunting. It is unlikely that *Homo* would have been able to make the transition to persistence hunting without first using endurance running for scavenging.

A wide array of evidence suggests that hominids were actively hunting, at least by the time that *H. erectus* appears circa 1.9 Ma (Potts, 1988; Bunn, 2001; Dominguez-Rodrigo, 2002; Braun, et al, 2010). The evidence for hunting includes a large proportion of bones with cut-marks indicative of flesh removal from regions of shafts that would not have had flesh had they been scavenged. In addition, many of these bones are from medium- to large-sized mammals. The bow and arrow and spear thrower were not invented until quite recently, probably after the origin of modern *Homo sapiens* (Shea, 2006). Evidence for hunting as early as two million years ago may therefore indicate the evolution of persistence hunting (Lieberman et al, 2009).

While modern hunter-gatherers have available to them a wide range of hunting methods, it is likely that persistence hunting would have been more important before the invention of the spear-thrower and the bow and arrow or the domestication of dogs. Without a spear thrower or bow and arrow it would have been very difficult for slow-running hominin hunters to get close enough to an animal to catch and kill it.

Hunting with Missile Weapons

The majority of animals brought down by recent hunter-gatherers was not killed upon initial contact, but were usually wounded, stunned or immobilized so that they were incapable of rapid or prolonged flight (Laughlin, 1968). Since the animal would have run out of sight, it would have had to be tracked down. We can therefore assume that hominins were not very successful at stalking and killing animals with missile weapons before they were able to track them down.

Furthermore, in woodland or uneven terrain, where visibility was limited, tracking would also have been important in locating animals. Animals are always alert for predators tracking them, looking back down their own trail. It is therefore not possible to stalk an animal using systematic tracking. Hunting with missile weapons would therefore have required a very advanced level of speculative tracking.

Even if we assume that Early Stone Age (ESA) hunters made spears, there is no evidence that they made stone-tipped or bone-tipped spears, which are capable of inflicting serious damage from a distance (Lieberman et al. 2009). Modern hunters use spears primarily to kill only disadvantaged prey, since the killing range of spears is very limited (Lieberman et al. 2009). Before the invention of the bow and arrow and the spear thrower, it is therefore unlikely that hunters were able to kill animals at a distance using spears.

The bow and arrow and spear thrower were not invented until quite recently, probably after the origin of modern *Homo sapiens* (Shea, 2006). The earliest evidence of bow and arrow was found at two sites in South

Africa and dates to 64 000 years ago (Lombard and Phillipson, 2010) and 71 000 years ago (Brown, et al, 2012) respectively. The bow and arrow is the most versatile hunting weapon, since a wide range of animals can be hunted with it, and it can also be used in a wide range of habitats, from open, semi-arid regions to tropical forests.

Natural Traps

Many nocturnal animals lie up in burrows by day. Once an occupied burrow has been found, it does not require much skill simply to dig the animal out or smoke it out. Hunters examine recently excavated burrows for fresh tracks leading into them to see if they are occupied.

An ability to track down fresh spoor may have greatly increased the efficiency of utilizing such natural traps. Animals like antbears may travel up to 30 km in a night (Smithers, 1983), so the spoor would have to be made just before sunrise when the animal was returning to its burrow. Animals such as pangolin, porcupine, caracal, African wild cat and brown hyaena may be driven out by smoke. Some animals, such as the jackal, bat-eared fox and honey badger cannot be driven out with smoke, while the antbear seals off the fire by blocking the burrow with sand, so that it must be dug out (Steyn, 1984a).

Artificial Traps and Snares

Artificial traps may use a variety of mechanisms. A trap may use the weight or momentum of the animal itself, the weight of a suspended object, or a spring. Perching birds can be caught by smearing a sticky substance, such as gum, onto branches. Pit traps would have concealed surfaces that collapse under the animal’s weight. Single nooses would catch animals by their own momentum, or spring-loaded nooses would make use of the flexibility of wood and of trigger mechanism.

Success in snaring depends on the hunter's ability to interpret fresh tracks and predict and influence an animal's movements and actions. It therefore required speculative tracking. Snares for steenbok and duiker are set across their paths or in breaks in unobtrusive barriers which have been erected to guide the animals onto the snare. For birds such as guineafowls, francolins, korhaans or bustards, the noose is pegged out around the bait. For each species a specific bait is used, depending on the bird's preference, and the snares are set in their favoured feeding grounds or close to their nests.

What is not known is the antiquity of trapping. While natural traps may have been used opportunistically by early hominins, artificial traps were possibly a relatively recent development. Although most traps are very simple in design, they are usually rather ingenious devices, so we can imagine that they could not have been invented before a fairly high level of creative intelligence evolved. The success of trapping (on land) also depends on the hunter's ability to interpret tracks and signs.

Ambush

Recent hunter-gatherers have been known to use blinds at waterholes or salt licks. Animals usually approach a waterhole from the downwind direction in order to scent possible danger, and are very wary when they drink. It would therefore be very difficult for a hunter to get close to such animals, so it is unlikely that hominins could have had much success from ambushing before they had effective missile weapons such as the bow and arrow or spear thrower. Even recent hunter-gatherers such as Australian aborigines were not very successful using this method (Pfeiffer, 1978). Ju/'hoansi hunters regarded hunting from blinds as not very effective, and preferred to track down an animal (Lee, 1979).

Hunting with Domesticated Animals

The domestication of dogs and horses for hunting made hunting much more efficient. However, this is a very recent development in the history of hunter-gatherers and would therefore not have played a role in the evolution of tracking.

The domestic dog (*Canis familiaris*) is considered to be the oldest domestic animal in the world. Recent genetic studies based on mtDNA suggest a single origin in Southeast Asia from numerous wolves less than 16 000 years ago as well as later hybridisation events in East Asia, the Middle East, Scandinavia and possibly North America (Klütsch and Savolainen, 2011). Horses were first domesticated 6000 years ago in the western part of the Eurasian Steppe, modern-day Ukraine and West Kazakhstan (Warmuth, et al. 2012).

Dogs were only introduced to the Kalahari in the late 1960's, but since their introduction they have dramatically changed hunting in the Kalahari (Liebenberg, 2008). In the southern Kalahari the gemsbok has been the most important species because of its size, its occurrence in fair numbers and the relative ease with which it could be hunted with dogs (Steyn, 1984a).

Even when hunting with dogs, hunters must have an understanding of tracking, animal behaviour and the environment (see Liebenberg, 1990a). On the basis of spoor interpretation of animal movements of previous days, the hunters will direct the dogs to bring them within range of the animals. Dogs usually only react to scent and sounds in their immediate vicinity. On their own they are only successful at running down small animals like bat-eared fox which have been flushed out in front of them. Generally dogs give chase to anything that moves, even springbok that they could never catch. To successfully locate and hunt gemsbok over long distances, the hunters must therefore direct the dogs.

In recent times hunters in the Kalahari have been hunting increasingly from horseback. The relative ease with which antelope can be hunted from horseback, especially when dogs are also used, has changed hunting dramatically wherever horses have been introduced. Although it is much more efficient, it does not require the skill, expertise and ingenuity required for persistence hunting or hunting with the bow-and-arrow.

Today the younger generation hunts mainly with dogs and horses, while traditional methods like persistence hunting and the bow-and-arrow are rapidly dying out.

The Evolution of Hunting and Gathering

As hominins developed new subsistence strategies in response to selective pressures, emphasis would have shifted to new strategies while retaining previous ones. An initial strategy based mainly on foraging plant foods, supplemented by casual scavenging and occasional predation, may have developed into one of gathering plant foods and systematic scavenging. Even with the development of hunter-gatherer subsistence, scavenging would still have played a role, since hunter-gatherers would have used every available strategy to exploit natural resources in the most efficient way.

In considering the possible evolution of hunting, it seems reasonable to assume that some of the simpler methods were developed earliest. In particular, persistence hunting requires no weapons and may have evolved long before missile weapons were invented. Persistence hunting may have played a critical role in the origin and evolution of hunting about two million years ago. In addition, persistence hunting may have been crucial in the evolution of tracking. Since the art of tracking is one of the most fundamental and universal factors in hunting, the evolution of tracking may have played an important role in the development of other forms hunting.

4

Persistence Hunting

Persistence hunting may have been the origin of hunting and represent a transition from predation to hunting, possibly about two million years ago. Early forms of persistence hunting that involved simple and systematic tracking would have been a form of predation, while more sophisticated forms persistence hunting that involves speculative tracking would have been the first form of hunting that involves creative human culture.

Persistence hunting takes place during the hottest time of the day and involves chasing an animal until it overheats and eventually drops from hyperthermia.

Various forms of persistence hunting have been recorded in the Kalahari. Small animals were knocked down with a throwing club and finished off at close quarters or, if the animal took off, run down. The young of small mammals were frequently run down on foot and caught by hand (Lee 1979). Slow-moving animals such as aardvark and porcupines were easily run down when encountered in open country (Silberbauer 1981). Animals such as eland, kudu, gemsbok, hartebeest, duiker, steenbok, cheetah, caracal, and African wild cat were run down in the hotter part of the day (Steyn 1984a; Marshall Thomas 2006). Duiker, steenbok, and gemsbok were run down in the rainy season and wildebeest and zebra during the hot dry season (Schapera 1930). It was believed that when a ruminant was prevented from chewing its cud during the chase it developed indigestion which eventually slowed it down, allowing the hunter to come close enough to kill it with spears (Heinz and Lee 1978).

Native American tribes also had various traditions of chasing down animals on foot (Nabokov 1981). Tarahumara chased deer through the mountains of northern Mexico until the animals collapsed from heat stroke and then throttled them by hand (Bennett and Zingg 1935; Pennington 1963). Paiutes and Navajo in the American Southwest are reported to have used this technique to hunt pronghorn antelope (Lowie 1924; Foster 1830, cited by Lopez 1981, 111). Aborigines of northwestern Australia are known to have hunted kangaroo in this way (Sollas 1924; McCarthy 1957).

Participatory Observations

Tracking involves intense concentration resulting in a subjective experience of projecting oneself into the animal. The tracks indicate when the animal is starting to get tired: its stride becomes shorter, it kicks up more sand, and the distances between consecutive resting places become shorter. When tracking an animal, one attempts to think like an animal in order to predict where it is going. Looking at its tracks, one visualizes the motion of the animal.

What is perhaps most significant when tracking an animal and projecting yourself into the animal, is that you at times *feel* as if you have become the animal – it is as if you can *feel* the motion of the animal's body in your own body. When tracking an animal you not only ask yourself "what is it doing or thinking?" – you also ask yourself "what is it feeling?" Is the animal feeling strong and healthy, as indicated by the length of its stride. Is the animal weak or injured, as indicated by signs of limping. Is the animal feeling tired, as indicated by signs of it dragging its feet in the sand. After running down a kudu in a persistence hunt, Karoha explained: "When the kudu becomes tired you become strong. You take its energy.

Your legs become free and you can run fast like yesterday; you feel just as strong at the end of the hunt as in the beginning." When the hunter finally runs the animal down, it loses its will to flee and either drops to the ground or just stands there, looking at the approaching hunter with glazed eyes. Karoha explained that when the kudu's eyes glaze over, it is a sign that it feels that there is nothing it can do any more: "What you will see is that you are now controlling its mind. You are getting its mind. The eyes are no longer wild. You have taken the kudu into your own mind." Karoha explained that he "controls" the kudu by anticipating and predicting its movements. "If the kudu decides to go this way, he will go there… if the kudu decides to go that way, he will go there…" Whichever way the kudu flees, it will find the hunter there… until it finally gives up. The hunter will then finish off the animal with a spear.

This *feeling like* the animal has a visceral, driven quality about it. At times you may feel like you have entered into a trance-like state. The excitement of this experience compels you forward, pushing you to your limits. When I ran the persistence hunt with !Nate, Kayate and Boroh//xao in 1990 (see *The Kudu Chase*, Chapter 2), I was so caught up in the excitement of the hunt that I was unaware of my own state of exhaustion and almost died of hyperthermia. Afterwards !Nate explained to me that a tracker must continually "test" his own body against that of the kudu – looking at the tracks of the kudu, the length of its stride and the way it kicks up the sand indicates how tired it is feeling. You must compare how your own body is feeling with what the kudu is feeling. Both Boroh//xao and Kayate dropped out of the hunt when they felt that they had reached their limits and that the kudu was still feeling stronger than them. Due to my inexperience (it was the first persistence hunt that I witnessed) I failed to compare "what the kudu's body felt like" with "what my own body felt like." I completely immersed myself into tracking the kudu, forgetting about my own body, so that I was unaware of my state of exhaustion. Only when I reached the dead kudu and relaxed, did I suddenly become aware that my legs were shaky and that I was completely exhausted.

In addition to the hypothetico-deductive reasoning required in speculative tracking (what is the kudu thinking), the subjective feelings experienced by the tracker (what is the kudu feeling) increases the chances of success of the hunt. It is your subjective feelings that drive you, pushing you to your limit. It is your subjective feelings that monitor your own condition against that of the kudu - failing which you may die of hyperthermia. This example demonstrates the value of empathy in the success of the hunt and therefore the adaptive value in terms of natural selection.

Observations of the Persistence Hunt

Before the invention of projectile weapons, persistence hunting was probably common. But in the past 20 years, the only hunters known to practice the persistence hunt have lived in the central and northern Kalahari, in the areas of Lone Tree, Bere and ≠Xade in Botswana, and Nyae Nyae and Caprivi in Namibia. I first recorded the persistence hunt in July 1985 when I accompanied four hunters, !Nam!kabe, !Nate, Kayate, and Boro//xao, from Lone Tree. We were separated during the hunt, however, and they told me only after the hunt how they had run down the kudu. I first witnessed this hunt on foot in August 1990 when I accompanied the same four hunters. Finally, on two expeditions with film crews, I followed the hunters in a vehicle. A total of eight attempts resulted in three kudus killed. In November 1998 I worked with Craig and Damon Foster in filming *The Great Dance* (I asked them to remove my name from the credits) and in October 2001 I worked with the BBC to film Karoha, !Nate, and /Uase (also from Lone Tree) persistence hunting for the last episode of David Attenborough's *Life of Mammals*.

The hunt takes place during the hottest time of the day, with maximum temperatures of about 39–42 ˚C. Before starting, the hunters drink as much water as they can. Then they run up to the animal, which quickly flees at a gallop, and track its footprints at a running pace. Meanwhile, the animal will have stopped to rest in the shade. The hunters must find the animal and chase it before it has rested long enough to cool down and restore core body temperature. This process is repeated until the animal is run down.

Before starting the hunt in August 1990, we drank as much water as we could. The water that was left was consolidated into one water battle (about one to two liters – the two-liter bottle was not full), which !Nate carried. The rest of us, Kayate, Boro//xao and myself carried no water. To lighten our load, !Nam!kabe, who was too old to do the hunt, carried the bows and arrows, clubs and hunting bags (as well as my camera and back pack) back to the camp. During the hunt none of us drank any water at all. When I caught up with !Nate at the end of the hunt, he told me that after he killed the kudu, he thought that Boro//xao and myself had gone back to the camp, so he and Kayate finished off the water.

On 15 May 2009 I interviewed /Ui /Ukxa (born 1931?) of //Auru village, /Kum //Xari (born 1936?) of N!om/xom village and Dabe Dahm (born 1949?) of N!ani ≠Xaiha village in the Nyae Nyae Conservancy in Namibia. I asked them how much water they carried when they ran down an eland. Before they had plastic bottles they used ostrich egg shells. /Ui explained that he carried only one ostrich egg shell full of water (about 1.25 liters). He could not carry two egg shells in his hunting bag, because they could easily break when he was running. From the morning to late afternoon he did not drink water. Even when running on an eland spoor he did not drink water. To run down an eland he would chase it from our camp site to the other side of Tsumkwe from the morning to just after midday or late afternoon (about 30 km in 3 to 6 hours, which is consistent with the GPS data I recorded in 2001). When he brought the eland under control, when it was getting tired, he would turn it around and chase it back towards the village so that he did not have to carry the meat too far. Only when the eland was almost dead, (after he had brought it under control and turned it around), did he drink some water. The old people who followed him would then bring him some more water.

In addition, it is worth noting that hunters do not drink much water during normal hunting activities. When I first started hunting with them, they used to tell me that I must not drink so much water – I must forget about water and just walk.

The hunts I observed involved three or four hunters starting the hunt, even when some of them were too old or not fit enough to complete it. A team of hunters can track much faster than one individual on his own. In the beginning the fittest runner may adopt an easy pace while the other hunters do most of the work tracking and running. While tracking as fast as possible, hunters are often slowed down when they lose the trail and struggle to find it again. When the others drop out, the fittest runner must pace himself to run down the animal on his own.

Table 1. Data on Persistence Hunts

Research Objective	Date	Hunter	Age	Species	Lowest and Highest Temperature (°C)	Distance (km)	Time	Average Speed (km/hr)	Result
Hunting on foot	July 26, 1985	!Nam!kabe	Not known	Kudu	Not recorded	Not recorded	Not recorded	Not recorded	Successful
Hunting on foot	August 29, 1990	!Nate	34	Kudu	Not recorded	Not recorded	< 2 hr	Not recorded	Successful
Filming persistence hunt	November 12, 1998	Karoha	35	Gemsbok	36–42	31	5hr05m	6	Failed
	November 18, 1998	Karoha	35	Kudu	32–39	35	3hr35m	10	Successful
Filming persistence hunt	October 5, 2001	Karoha	38	Kudu	Not recorded	25.5	4hr06m	6.2	Failed
	October 6, 2001	Karoha	38	Kudu	Not recorded	33	4hr57m	6.6	Successful
	October 9, 2001	Karoha	38	Kudu	35–41	17.3	3hr40m	4.8	Failed
	October 10, 2001	Karoha	38	Kudu	35–42	20.5	4hr52m	4.2	Failed
	October 12, 2001	Karoha	38	Kudu	39–42	35.2	6hr38m	5.3	Failed
	October 13, 2001	Karoha	38	Kudu	Not recorded	25.1	3hr50m	6.3	Successful

The shortest hunt I witnessed lasted less than two hours (the exact time is not known, since I had to catch up with the hunter) (table 1). In this hunt !Nate ran the entire way, although he sometimes slowed down when he lost the spoor. However, after the hunt !Nam!kabe said that they did not have to run that fast and that it was possible to run down a kudu if the hunter walked some of the time. On one successful hunt in 1998 the distance covered by Karoha was measured with the vehicle odometer. The hunt took 3 hours 35 minutes to cover about 35 km, for an average speed of about 10 km/hr. On two successful hunts in 2001 a global positioning system was used to record the route followed by Karoha. One hunt took 3 hours 50 minutes to cover 25.1 km, for an average speed of 6.3 km/hr. The other took 4 hours 57 minutes to cover 33 km, for an average speed of about 6.6 km/hr.

Table 2. Field Notes on Failed Persistence Hunts

October 9, 2001		October 10, 2001		October 12, 2001	
Time	Notes	Time	Notes	Time	Notes
12:02:43 P.M.	Start hunt	10:31:29 A.M.	Start hunt	11:35:54 A.M.	Start hunt
12:08:04 P.M.	Hunting magic	10:42:20 A.M.	Run	11:39:48 A.M.	Kudu hunting magic
12:20:36 P.M.	35 degrees	11:03:18 A.M.	Spoor joins another 2	11:43:40 A.M.	39 degrees
01:00:16 P.M.	Run	11:10:49 A.M.	See 4 to 5 young bulls	11:48:35 A.M.	Run
01:18:52 P.M.	Walk	11:36:04 A.M.	1 missing go back to look for spoor	11:53:12 A.M.	41 degrees
01:19:49 P.M.	Run	11:40:48 A.M.	35 degrees	12:36:55 P.M.	Walk
01:24:24 P.M.	Walk	12:01:38 P.M.	Find missing spoor which turned away	12:43:21 P.M.	3 kudu split into 2 and 1
01:29:05 P.M.	Run	12:08:15 P.M.	Spoor shows it is getting tired, start run	12:59:56 P.M.	Run
01:47:45 P.M.	Run	12:56:54 P.M.	Walk thick bush	01:02:02 P.M.	Kudu separated
02:04:56 P.M.	Walk	12:59:19 P.M.	Run	01:23:10 P.M.	42 degrees
02:14:08 P.M.	39 degrees	01:00:40 P.M.	Walk	01:34:21 P.M.	Kudu mix with females
02:21:10 P.M.	Run	01:03:12 P.M.	Run	01:46:02 P.M.	!Nate finished
02:31:21 P.M.	Walk	01:07:42 P.M.	Run	01:48:36 P.M.	Kudu tired
02:32:43 P.M.	Run	01:23:03 P.M.	41 degrees	01:56:40 P.M.	/Uase finished
02:39:36 P.M.	41 degrees	01:47:31 P.M.	Walk	03:12:54 P.M.	Mix with females
02:48:18 P.M.	Female	01:53:55 P.M.	Kudu walking slowly	03:36:28 P.M.	40 degrees
02:52:07 P.M.	Lost spoor	01:57:22 P.M.	Refill water run	03:48:00 P.M.	Herd of hartebeest mix
02:54:07 P.M.	Run	02:04:48 P.M.	38 degrees	03:58:14 P.M.	1 male 1 female
03:04:35 P.M.	Walk	02:14:02 P.M.	40 degrees	04:58:40 P.M.	Hartebeest follow kudu spoor
03:32:30 P.M.	Lost spoor	02:17:55 P.M.	Wash faces	06:13:01 P.M.	Leave spoor for tomorrow
03:42:51 P.M.	Abandon chase	02:40:01 P.M.	39 degrees		
		02:50:21 P.M.	41 degrees		
		02:50:45 P.M.	!Nate finished		
		02:59:38 P.M.	42 degrees		
		03:23:40 P.M.	Lost spoor in herd of eland with babies		

An average speed of 6.3 km/hr may not seem very fast, but the challenge to the hunter is not so much the speed as the difficult conditions that need to be overcome, including extreme heat, soft sand, and sometimes thick bush. Depending on conditions, hunters may run a fast pace throughout the hunt, or may vary their pace, sometimes walking to regain their strength. The hunter may be slowed down when he loses the trail. The most difficult task for the tiring hunter is keeping on the right track when the animal joins the rest of the herd again, since its tracks must be distinguished from those of the other animals. When the animal is still running strongly, this can be very difficult, but when it starts to show signs of tiring it becomes easier to distinguish its tracks. Another difficulty is that the animal may circle back onto its own tracks and the hunter must decide which set of tracks to follow. The hunter does not always run on the tracks but often leaves the trail in order to pick it up ahead, and a number of times the hunter lost time following the wrong trail and then going back to find the right one. The trail may also be lost when herds of other antelope species cross the tracks. Losing the tracks was the main reason the hunters gave up in unsuccessful attempts (see table 2). Figure 2 plots the route of Karoha running down a kudu bull in October 2001, showing the kudu crossing back over its own tracks a number of times and joining other groups of kudu bulls.

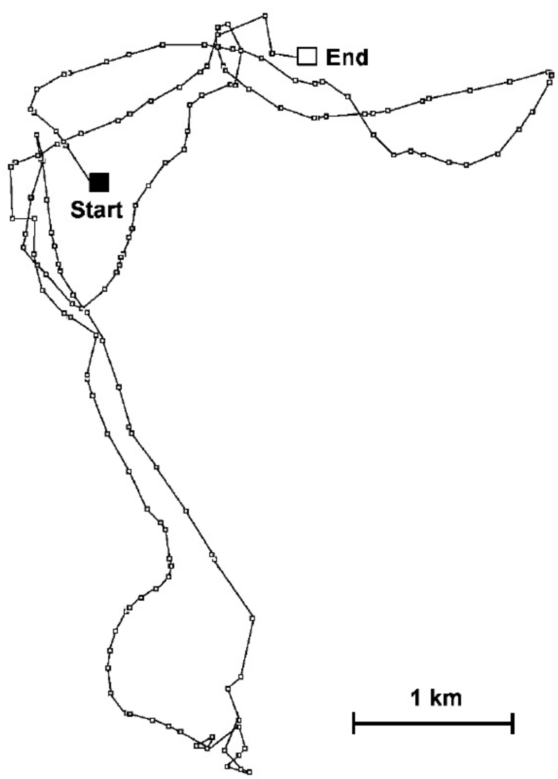


Fig. 2: The route of Karoha running down a kudu bull on October 13, 2001, plotted with a global positioning device.

Local Knowledge and Practice

!Xo and /Gwi hunters at Lone Tree maintain that they concentrate on different species at different times of the year. They say that steenbok, duiker, and gemsbok can be run down in the rainy season because the wet sand forces open their hoofs and stiffens the joints. This is consistent with what Schapera (1930) reported. Kudu, eland, and red hartebeest can be run down in the dry season because they tire more easily in loose sand. Kudu bulls tire faster than cows, perhaps because of their heavy horns. Kudu cows are run down only if they are pregnant or wounded. Animals weakened by injury, illness, or hunger and thirst are also run down. When there is a full moon, animals are active all night, and by daybreak they are tired and easier to run down. The best time for the persistence hunt is at the end of the dry season (October/November), when animals are poorly nourished. During August/September, insects (*!oam/neli*) bite the kudu, making them sick. After the first rains (November/December), the dry leaves make "hard balls" in the stomach of the kudu that give it diarrhea. After it has rained, it is easier to follow the fresh tracks in the wet sand. In February/March, the mixture of green vegetation with dry vegetation can cause diarrhea, making it easier to run animals down, but cloudy, cool days make it more difficult. In the winter months (June/July) the shorter days make hunting difficult. However, hunters maintain that it is possible to run down animals at any time of the year (I recorded one persistence hunt in July).

When running down a herd of kudu, trackers say that they look to either side of the trail to see if one of the animals has broken away from the rest of the herd and then follow that animal. The weakest animal usually breaks away from the herd to hide in the bush when it starts to tire, while the others continue to flee. Since a predator will probably follow the scent of the herd, the stronger animals have a better chance of outrunning it, while the weaker animal has a chance to escape unnoticed.

Endurance Running by Humans

Endurance running may be a derived capability of the genus *Homo* and may have been instrumental in the evolution of the human body form (Bramble and Lieberman, 2004).

Walking alone cannot account for many of the derived features of early *Homo*, because the mass-spring mechanics of running, which differ fundamentally from the pendular mechanics of walking, require structural specializations for energy storage and stabilization that have little role in walking. Such specialized structures include: an extensive system of springs in the leg and foot that effectively store and release significant elastic energy during running; short toes; enlarged gluteus maximus and spinal extensor muscles that contract strongly to stabilize the trunk in running but not in walking; enlarged semicircular canals that sense pitching motions of the head necessary to stabilize gaze; and a narrow waist in combination with a low, wide, decoupled shoulder girdle that have essential stabilizing functions in running (Bramble and Lieberman, 2004).

Perhaps the most critical factor in the success of persistence hunting is the fact that humans cool their bodies by sweating while running. If an antelope is forced to run in the midday heat on an extremely hot day it overheats and eventually drops or simply stops running from hyperthermia, allowing the hunter to kill it with a spear or other weapons. The normal core body temperature of eutherian mammals is 36–38 degrees C (Schmidt-Nielsen, 1990), and the lethal core temperature of these mammals is 42–44 degrees C (Adolph 1947). Most medium-sized-to-large mammals rely on evaporative cooling in the oral cavity to maintain body temperature while running (Richards 1970; Taylor 1974, 1977). In humans the critical thermal maximum, beyond which lifethreatening damage develops, has been estimated at 41.6–42 degrees C (Kosaka et al. 2004), but humans can tolerate heat stresses well above this limit (Kenney, DeGroot, and Holowatz 2004).

Humans not only developed as long-distance runners especially well adapted to run in extreme dry heat in the middle of the day, but also were able to drink infrequently and conserving body sodium stores. By delinking thirst from the actual water requirement during exercise, humans were able to exercise in the heat while delaying the need to drink until after exercise when, in the safety of their home base and with access to a more abundant water source, they could leisurely replace the fluid deficit generated by their daily activities in the heat. This adaptation also allowed the development of a smaller stomach and intestine, leading to a more linear design, further reducing heat gain in the midday heat and allowing more efficient running (Noakes, 2012).

Carrier (1984) and Bramble and Lieberman (2004) explain how humans are able to run down large quadrupedal mammals such as antelope. Some of the most important points may be summarized as follows: In mammals generally, evaporative cooling is accomplished by two separate mechanisms: (1) respiratory evaporation occurring at the nasal mucosa, buccal, and tongue surfaces (panting) and (2) evaporation of sweat from the general body surface. The flexibility and possibly the total effectiveness of panting as a means of evaporative cooling may be limited in a running mammal. Quadrupeds cannot pant and gallop at the same time. So if you make an animal gallop for long periods in the heat it will overheat (Bramble and Lieberman, 2004). The amount of heat that can be lost through evaporation from the respiratory surfaces severely limits the maximum rate of heat dissipation during running in animals that rely solely on panting (Carrier 1984; Taylor and Rowntree 1974). The sweat glands of humans are distinctive for the high secretory level at which they operate. No other species is known to sweat as much per unit surface area as humans (Eichna et al. 1950; Schmidt-Nielsen 1964; Newman 1970). The great increase in eccrine (as opposed to apocrine) sweat glands and their copious secretions have permitted modern humans to undertake vigorous exercise in hot environments. The rate at which heat is lost in running humans is greatly increased by their relative lack of hair and by convection during running. The combination of well-developed sweat glands and the relative absence of body hair make it probable that running humans display very high thermal conductance, with maximal values well above those of most cursorial mammals (Carrier 1984).

In contrast to most quadrupeds, humans increase speed during endurance running mostly by increasing stride length. Long stride lengths in humans are made possible by a combination of effective leg springs and relatively long legs (Bramble and Lieberman 2004).

Data on the metabolic benefits of changing gaits for ponies suggests that quadrupedal mammals have specific speeds at which energy expenditure is minimized for each of their various gaits (Hoyt and Taylor 1981). In contrast, the energy required for a running human does not depend on speed (Boje 1944; Margaria et al. 1963; Cavagna and Kaneko 1977). A constant cost of transport could provide humans with the option of running at a wide variety of speeds, while quadrupeds appear to be specialized for a narrow range of speeds within each gait (Carrier 1984).

When chased, the animal outruns the hunter and then stops to rest in the shade. It is forced into an intermittent running pattern by the contrasting needs to avoid the hunter and to avoid fatigue and heat stress. Although intermittent running provides brief rest periods, it may be less economical than continuous running (Carrier 1984). Compared with continuous exercise, intermittent exercise has (for humans) also been shown to elevate core body temperature and decrease evaporative heat loss as a result of reduced sweating (Ekblom at al. 1971). Whether the prey ran at a pace set by the hunter or chose to run intermittently, the end result would have been inefficiency. A hunter whose cost of transport did not vary with running speed would likely have had a substantial advantage over a prey animal with restricted, energetically optimal speeds in each gait (Carrier 1984). During the persistence hunt, the hunter needs to run at a fast pace when tracking is easy but slow down when tracking is difficult—sometimes losing the trail, sometimes walking to regain strength. His speed is determined not only by his physical speed and endurance but also by how fast he can track the animal. Flexibility in running speed allows a human hunter to pursue an animal persistently at various speeds, depending on his fitness, the heat, and varying tracking conditions.

Relative Success Rates of Hunting Methods

In July 1985 I worked with Bahbah, Jehjeh, and Hewha at Ngwatle Pan in Botswana. During one field trip, five days of hunting resulted in one gemsbok and two bat-eared foxes killed by hunting with dogs. Although five days may not be enough to get a reliable estimate of success rate, hunting with dogs is evidently much more efficient than hunting without them. Four field trips adding up to 46 days of hunting focused on hunting with bow and arrow, club, and spear (without dogs). In July 1985, August 1990, February and March 1991, and June 1992 I worked with !Nam!kabe, !Nate, Kayate, /Uase, and Boro//xao from Lone Tree, and in these periods two persistence hunting attempts resulted in the killing of two kudus. There were 41 attempts at bow-and-arrow hunting, which involved following fresh tracks and stalking steenbok, duiker, springbok, hartebeest, wildebeest, kudu, and gemsbok. Of these, 39 attempts failed. One wildebeest and one duiker were killed with bow and arrow. Animals killed with club and spear included aardvark, porcupine, and gemsbok (a calf). These involved following fresh tracks and killing animals dug out of their burrows or surprised where they were sleeping under bushes. Eleven attempts resulted in the killing of two aardvark, two porcupines (killed in one attempt), and one gemsbok calf. Animals killed with a springhare probe included three springhares and one ground squirrel in 29 attempts. No reliable data on the success rate of snaring were obtained.

Table 3 shows the meat yield, estimated, following Lee 1979), to be 50% of the weight of the animals hunted. Meat yields in kilograms per day hunted offer an estimate of the relative efficiency of the different hunting methods.

Table 3. Meat Yield (kg/day)

Method	Days	Species	Weight (kg)	Edible Yield (kg)	Number	Yield (kg/day)
Dogs	5	Gemsbok	240	120	1	24
	5	Bat-eared fox	4	2	2	0.8
Total						24.8
Persistence hunt	46	Kudu	230	115	2	5
Total						5
Bow and arrow	46	Wildebeest	250	125	1	2.7
	46	Duiker	20	10	1	0.2
Total						2.9
Club and spear	46	Aardvark	52	26	2	1.1
	46	Porcupine	18	9	2	0.4
	46	Gemsbok calf	10	5	1	0.1
Total						1.6
Springhare probe	46	Springhare	3	1.5	3	0.1
	46	Ground squirrel	0.6	0.3	1	0.007
Total						0.1

Note: Figures rounded to the nearest 0.1 kg/day.

Table 4 presents data obtained for hunting methods on seven field trips with three different research objectives. The number of animals killed per number of days hunted gives an indication of the success rate per day.

Table 4. Success Rates of Different Hunting Methods

Research Objective	Method	Days Hunted	Attempts	Successful	Success Per Attempt (%)	Animals Killed/Day	Yield (kg/day)
Hunting with dogs	Dogs	5	5	3	60	0.6	24.8
Hunting without dogs	Persistence hunt	46	2	2	100	0.043	5
	Bow-and-arrow	46	41	2	5	0.043	2.9
	Club and spear	46	11	5	45	0.109	1.6
	Springhare probe	46	29	4	14	0.087	0.1
Filming persistence hunt	Persistence hunt	N/A	8	3	37	N/A	N/A
Amended data[a]	Persistence hunt	N/A	5	4	80	N/A	4
Extrapolated data[b]	Snaring	N/A	N/A	N/A	N/A	N/A	5

[a]Omits persistence hunts attempted for the sake of filming which would not have been attempted under normal hunting conditions.
[b]Estimate based on data published by Lee (1979).

Data obtained while filming the persistence hunt give some indication of the success rate per attempt, but the number of days hunting is inapplicable. The success rate while filming may have been lower than normal, since the hunters were under pressure to attempt hunts that they might not have performed under normal conditions. For example, the failed gemsbok hunt of November 12, 1989, was attempted only after a long debate in which Karoha expressed his reservations. (They would normally run down gemsbok in the rainy season, not the dry season.) On

October 6, 2001, the camera crew did not film the moment when the kudu collapsed and asked Karoha to repeat the hunt. A hunter would not normally attempt another persistence hunt three days after a successful one. If the data from the research and filming expeditions are combined, omitting the hunts that would not have been attempted if it were not for the sake of filming (those of November 12, and October 9–13, 2001) then the amended data in table 4 would include four successful hunts out of five attempts, giving an 80% success rate. The amended yield (4 kg/day) is 80% of the yield estimate based on the two hunts observed while hunting on foot.

It is possible that the success rate of persistence hunting has deteriorated in the past 20 years as the last few hunters who have been practicing it get older. It may be significant that in 1990 they ran for the entire hunt, killing the kudu in less than two hours, while in 1998 and 2001 the hunter sometimes walked. !Nam!kabe, who performed the hunt in 1985, has died. His son !Nate, who ran down the kudu in 1990, when he was 34, is now unfit to do so. Karoha, who was 35 when he performed the hunt in 1998 and 38 when he did so in 2001, may soon be too old. As far as is known, Karoha may well be the last hunter in the central Kalahari who has been practicing the persistence hunt. However, since only three individuals were observed, the apparent deterioration could simply be individual variation in skill.

Recent hunter-gatherers utilize a range of hunting methods depending on conditions and circumstances. My observations and data from Lee (1979) suggest that the highest success rate and the highest meat yield are achieved by hunting with dogs. A relatively high success rate is also achieved with snaring small antelope (steenbok and duiker) and birds (korhaan, kori bustard). Although I obtained no reliable data on using snares, a rough extrapolation can be made using data from Dobe, Namibia, published by Lee (1979, 267). Over a 28-day period, hunting with dogs produced a meat yield of 151.1 kg while using snares produced 32.1 kg. Assuming that the hunters I worked with had a similar success rate, the equivalent meat yield from snaring per days hunted would be about (32.1/151.1) x 24.8 = 5.26, or roughly 5 kg/day hunted (Table 4). This would be about the same as the meat yield for persistence hunting.

Digging out animals sleeping in burrows or killing animals sleeping under bushes with clubs and spears has a relatively high success rate compared with other methods. However, the meat yield is relatively low. Using the springhare probe for small mammals in burrows produces the lowest meat yield. Larger animals (when hunting without dogs) would be either pursued with bow and arrow or run down in the midday heat.

The bow and arrow is the most flexible method, allowing a large number of opportunities from small antelope to the largest, including eland and giraffe. However, for most of the hunts I witnessed, the success rate per attempt was very low. Often, when tracking one animal, the hunters would abandon the trail for a more promising lead or to dig up an animal in a burrow. Hunters would often attempt a stalk and not get close enough (25–30 m) to shoot, or, when they did get close enough, the arrow would miss the target. Even when they did hit the target, it might take hours or even days to track the wounded animal, and sometimes the animal would recover and escape or be finished off during the night by other predators or scavengers. Because of the opportunistic nature of hunting and gathering, hunters are continuously changing their methods depending on changing opportunities. They may start out on a bow-and-arrow hunt and end up digging out an aardvark. It requires many attempts to kill an animal with a poisoned arrow.

In contrast, persistence hunting is limited to fewer species and favorable conditions for it occur less often, but the success rate per opportunity seems to be much higher. When the conditions are right, hunters appear to be more confident of succeeding with the persistence hunt than with the bow and arrow. For example, the persistence hunt I witnessed in August 1990 took place at the end of the dry season, when the thick dry grass made it difficult to stalk silently. After a number of failed attempts with the bow and arrow, the hunters had expressed confidence that they had a better chance of running down the kudu.

The fact that the duration of persistence hunts varies considerably may explain why the success rate per attempt is much higher than for bow-and-arrow hunting. When hunting with bow and arrow, the hunter may spend a considerable period of time tracking and stalking an animal, but in the end he has only one chance. When conditions are right for persistence hunting, the hunter has a much larger margin of error. As long as he is able to pursue the animal at a reasonable pace and not lose the trail, whether it takes two hours or five hours he has a good chance of running it down.

Compared with other hunting methods, persistence hunting is, given the right conditions, an effective method with a relatively good success rate and meat yield. The data presented suggest that it produces a higher meat yield than hunting with bow and arrow, clubs and spears, or springhare probes and about the same as snaring. Only hunting with dogs produces a significantly higher meat yield.

5

The Art of Tracking

This chapter will look at some of the key aspects of tracking. A more in depth overview can be found in *The Art of Tracking: The Origin of Science* (Liebenberg, 1990a) and *Practical Tracking* (Liebenberg et al, 2010).

Lion Tracking

Just after four o'clock in the afternoon !Nam!kabe decided to go out with his bow-and-arrow to see if he could shoot a steenbok or a duiker. I went with him, while !Nate, Kayate and Boroh//ao stayed in the camp. About two hundred meters from our camp !Nam!kabe shouted "lion!," and a lioness jumped up in front of us, bounding off into the bush. Shouting to chase away any other lions that may be hidden in the bush, !Nam!kabe and I went to look at her tracks to see what she was doing there. As he studied the tracks, !Nam!kabe explained: "The lioness lay here, jumped up and ran away… this is a large female… she lay here and saw us coming and was afraid of us. We found her here near our camp… she stays here… I do not know if she has eaten, come, we must follow her tracks and see if she killed an animal, then we can chase her away and take her meat." But as we followed her tracks it was clear that she had not killed anything. "What sort of lioness is this that cannot kill a gemsbok? She stays here among all these animals, but cannot kill anything… there are many gemsbok, hartebeest and kudu…this lioness walks amongst all these animals to come and stalk our camp… she will not leave us alone… it is in the day, why does she come and lie here with us like a dog? Let us leave the tracks and go and tell the others, because we will not sleep tonight. You *and me, we do not sleep well at night because we have to look after the fire while the others just sleep. We must go back and tell the others who do not help us keep the fire going at night. This lioness is here with us… don't think that she ran away… she stalks us here in the thick bush."*

When we returned to our camp, the younger hunters decided to track the lioness. They took the tin, which we used to boil water in, and put some stones in it – this is so that they could make a loud noise by shaking the tin. At about five o'clock we set out with !Nam!kabe, his son !Nate, Kayate and Boroh//xao, armed with spears and throwing sticks. From where we flushed the lioness, we could see from her tracks that she circled downwind to look at !Nam!kabe and myself as we were studying her tracks. Kayate said we should chase her away: "We must follow her tracks and shout at her to chase her away, because she is too close to our camp." As we followed her tracks, they would start to shout at her and shake the tin, the shouting and noise becoming louder and louder, working each other up, and then they would shout abusive insults - "you big penis!"- at her and burst out laughing – alternating aggressive shouting with tension relieving humor and laughter. After tracking her for a while, !Nate suggested that we should not follow her tracks (to see where she had gone), we must rather backtrack to see where she had come from. "If she got our wind and came from a distance straight to our camp, then we will not be able to sleep tonight… and we cannot follow her when the sun is so low, because when we find her she will fight with us… and we must go back to collect enough wood to keep the fire going all night long."

That night, as we sat around the fire, !Nam!kabe told the story of when they encountered a lioness with cubs: "A lioness with small cubs is not right in the head. My grandfather and father-in-law and myself… there were three of us… were hunting springhares with our springhare hooks. We were hitting tree trunks with our clubs, looking for honey (hitting the trees to see if bees come flying out). My grandfather was walking some distance ahead of us when he found the lioness with her cubs. When we caught up with him he was fighting with the lioness, so we went to help him. As the lioness charged us we shouted and threw sticks at her… then she would go back to move her cubs away and then come back to charge us again. And we threw her with sticks, shouting at her. She would go back and move her cubs a little further away and again came back to fight with us. Every time she *came back we would throw sticks at her… and the last time she came so close she kicked the sand up in our faces! Then she went back to her cubs to lie in the shade of some large trees. We told her – if you are not right in the head, then we are also not right in the head! So we left her there and went home. When we hunt here in this place we must know that one day you will walk into a lioness with cubs, because the bush is very thick here."*

Throughout the night they told stories of tracking lions with safari hunters, and encounters with lions, times when they had to sleep in trees. Often they would laugh at each other when recounting their experiences. Then there were quiet times when we would just stare into the fire. And once in a while, !Nam!kabe would feel a burning sensation under his armpits and say that the lioness must be near our camp, stalking us from the downwind side. Then all hell would break loose – they shouted and made loud noises, banging sticks against pots and tins, and shaking the tin with stones in it. Then they would throw sticks into the dark, downwind from us where they thought the lioness might be. And when the shouting and noise reaches a crescendo, they would hurl abusive insults at the lioness and burst out laughing. Then things would simmer down and we would be quiet for the next hour or two. This shouting, banging of pots and throwing sticks into the dark were repeated a number of times through the night until the dawn finally broke.

The next morning we went out to track the lioness to see what she was up to during the night. We found the place where she lay down until sunset. From there she got up and circled downwind of our camp, coming towards our camp. But as she came near our camp, she stopped. !Nate pointed at her tracks: "She stood here and heard us making a noise – these are the hind feet and here are the front feet… as she stood and listened, she thought to herself: 'if I go there those people will kill me… if I do not go back I will die here tonight…' then she turned around and went back to where she came from."

We then followed her tracks to see where she was going. It was important to see how far she had gone and whether she had left the area or not. We found the place where she had slept for the night. Then she got up and started to move on. Boroh//xao pointed out where she had defecated: "Look how dry her dropping are – they are like little stones – she had not eaten for days. This is why she has been *stalking humans." She was walking with twists and turns through the thick bush, sometimes walking and sometimes moving at a trot. Boroh//xao explained that: "She is moving through the thick bush where people cannot easily go in order to avoid us." We followed her tracks for most of the day, and as we moved through thick bush, a loud roar exploded a few meters from us! Everyone burst into loud shouting, while aggressively moving in towards the noise… and then a few moments later they all burst out laughing. We had surprised a kudu bull, who gave its loud hoarse bark – expecting to walk into the lioness any moment, the kudu sounded just like a lion!*

At this point they were satisfied that the lioness had moved out of the area and was no longer a threat to us. It was getting late, so they decided to see if they could hunt something on the way back.

Track Identification

The ability of Kalahari hunter-gatherers to interpret tracks and signs are cultivated over a lifetime and developed to an exceptionally high degree. For example, men and women are able to identify the footprints of an individual person. While women usually have smaller and narrower feet than men, the size and shape of each individual's feet differ in subtle ways. Someone with a slender body build has slender feet, while someone who is stocky has shorter and relatively broader feet. A person's trail is also characterized by the way he or she treads and walks. It may be characterized by the length of stride, the way the ball of the foot is twisted, the way the toes may be pointing inwards or outwards, the way the toes are splayed or curled in, the way the foot throws up sand or characteristic scuff marks. Each person has an individual mannerism when walking which can be identified in his or her tracks. This enables experienced trackers to identify an individual's tracks even in soft sand where the exact shapes of the feet may not be clear.

!Xõ hunters can identify the tracks of most animal species larger than mongooses, while the tracks of very small animals such as mice, small birds, reptiles and arthropods can be identified as belonging to a member of a group of animals. Even in loose sand, where footprints are not very distinct, the tracks of different mongoose species can be identified and steenbok tracks can be distinguished from duiker tracks.

Their ability to identify tracks goes far beyond their immediate needs in hunting. When I showed a group of !Xõ trackers my track illustrations (Liebenberg, 1990b), one tracker identified the tracks of a large ant, which one would not expect to be relevant to hunting. They also identified the tracks of many of the small animals, such as that of beetles, scorpion, millipede, legless skink and lizards. Among the illustrations of bird tracks, they not only identified the dove tracks, but specifically singled out the Namaqua dove track as being that of a Namaqua dove. My spoor illustrations generally caused great excitement, and women and children enthusiastically took part in the discussions. The women seemed just as knowledgeable on spoor as the men and in fact one young woman, !Nasi, put the men to shame. Women are also highly skilled trackers (Biesele and Barclay 2001).

Sometimes hunters do make mistakes in identifying tracks of smaller animals or rarely seen animals. After estimating the age of the tracks of an ostrich, a tracker pointed to a "mouse" footprint superimposed on that of the ostrich track to substantiate his claim. Although the details of the little footprint in the soft sand were too indistinct to distinguish, the trail was not that of a mouse, and after studying it more closely, I pointed out to him that it was the track of a small bird. When he realized his mistake, he said that he had looked too quickly. He explained that one must not look too quickly at tracks, because you will "see it differently." One must, he maintained, study tracks carefully and think before you make a decision. He was probably so anxious to substantiate his estimate of the age of the ostrich track that his mind was prejudiced to "recognize" the small bird track as a "mouse track" (see *Recognition of Signs* below).

The sex of an animal is usually distinguished by the size and shape of the footprints. Where males are larger and more massive than females, their tracks are larger and the footprints of the forefeet are relatively broader than those of females. The sex of an animal is also determined by association (for example, a female with a calf) or the relative position of urine to the back feet or faeces.

The age of a growing animal is indicated by the size of the tracks which increases until the animal reaches adulthood and correlates with the size of the animal. The edges of the hoofs of young antelope will also be clean and sharp, and the toes may splay out because it treads gently. As an antelope grows older the hoofs become worn and the edges may be chipped. The hoofs of an old antelope may be very worn and blunted with age, and it may show signs of weakness in the way it walks. The condition of an animal is indicated by the way it treads and walks. For example, a healthy, fat animal will tread deeply and firmly, while a weak, lean animal may tread weakly and drag its feet, or show signs of limping.

With regard to large animals such as kudu, gemsbok and eland, hunters can identify the tracks of individual animals in the same way as they identify the tracks of individual persons. The sizes and shapes of each individual animal's footprints differ in subtle ways. When hunting with !Xõ hunters, I have found that as you track an individual animal you get to a point where you become familiar with its tracks and intuitively "feel" that you are on the right animal's trail. When you have lost the trail, the moment you find it again it "feels right," even in soft sand where details of the tracks may be indistinct.

Recognition of Signs

The city dweller may find it difficult to appreciate the subtlety and refinement of the tracker's perception of signs. In cities, "signs" (such as in advertising, clothing, noise, etc.) all compete with each other for one's attention in an artificial environment. This results in a blunting of the senses, so people lose their sensitivity to their environment. In contrast, animals in nature have evolved to be inconspicuous and tracks and signs are all very subtle, so the tracker must develop a sensitivity to the environment. The tracker's ability to recognize and interpret natural signs may therefore seem quite uncanny to the uninitiated city dweller.

To be able to recognize signs the tracker must know what to look for and where to look for it. Someone who is not familiar with tracks and signs may not recognize them, even when looking straight at them. It may seem as if no signs are present at all. For example, when tracking through grass, trackers will look for trampled grass, or if the ground is covered with pebbles, they will look for pebbles displaced from their sockets. To recognize a specific animal's tracks, the tracker will look for signs characteristic of that animal.

In order to recognize slight disturbances in nature, trackers must know the pattern of undisturbed nature. They must be familiar with the terrain, the ground and the vegetation in its natural state. Only when they are familiar with all these aspects will they be able to recognize very subtle disturbances in it. For example, a disturbance may be revealed by colour differences of overturned pebbles, stones and leaves, whose underside is usually darker than the sun-bleached top side.

In order to recognize a specific sign, trackers may have a preconceived image of a typical sign. Such a typical sign may be defined by certain characteristics which enable the trackers to recognize specific patterns in signs with corresponding characteristics. Without such preconceived images many signs may be overlooked, but with a preconceived image of a specific animal's track in mind, trackers may tend to "recognize" signs in markings that may be made by another animal, or even in random markings. Their minds will be prejudiced to see what they want to see, so in order to avoid making such errors they must be careful not to make decisions too soon. Decisions taken at a glance can often be erroneous.

While the existence of preconceived images may help to recognize signs, the tracker needs to avoid the preconditioned tendency to look for one set of signs in the environment to the exclusion of all others. This is illustrated by naturalists who have trained themselves to detect the smallest signs of a particular speciality but who miss out almost everything else.

Factors that determine the degree of skill required to recognize, identify and interpret spoor are the *information content* of signs, the *sparseness* of signs and the number of *proximate signs*.

The *information content* of a sign can be defined as the amount of information that can be derived from it. Well-defined footprints in damp, soft ground may provide detailed information on the identity, sex, size, mass, age, condition and activities of an animal; a barely perceptible scuff mark on hard substrate may include nothing more than the fact that some disturbance has occurred. Inhibiting factors on the information content of signs include: the relative hardness of the substrate; the presence of loose sand; the density of vegetation cover; and the action of wind, rain and snow. Even the most indistinct markings can give an indication of the type of animal that made them. Several indistinct markings may together provide more complete information. Each marking may provide different information. Taken together their relative position to each other may indicate the size and gait of the animal. A group of four indistinct scuff marks can be distinctive of a hare, or three claw marks can be distinctive of the honey badger.

It is also important for trackers to recognize when there are no signs at all. When the terrain is very hard, trackers need to be able to tell if the animal would have left some signs if it did in fact pass that way. This is important since trackers need to know when they are no longer on the trail. For example, an animal may have followed two potential routes. If the tracker can see that there are no signs where there should have been signs, then the animal probably followed the other route.

The *sparseness* of signs depends on the substrate, vegetation and weather conditions. On soft, barren substrate every footprint may be clearly defined and it would not require much skill to simply follow the trail. On harder substrate, footprints may not be well defined, while on very hard substrate or on a rocky surface, spoor may be hardly perceptible at all. The sparseness of signs also depends on the extent to which signs have been obliterated by wind, rain or snow.

While footprints are more difficult to see on ground covered by vegetation than on relatively barren ground, depending on the density of the vegetation cover, signs in the vegetation itself may indicate the animal's route. The trail created in long grass may also be distinctive of the animal. Antelope, whose legs are long and thin, may leave a barely perceptible trail in grass, while a lion, a porcupine, or a human may leave a very clear path through the long grass.

In rocky terrain, an animal may leave hardly any signs at all, but it may still be possible to follow its trail through the rocks and boulders my imagining the easiest route it would follow. In rocky, mountainous terrain it may be possible to follow an imaginary route, following the contours and in between obstacles, and finding signs along the route to confirm the trail.

Proximate signs may be defined as signs made by other animals in the vicinity of the spoor being followed. These signs may have been made before, at the same time, or after the spoor of the animal being followed, and if superimposed onto each other could give an indication of the age of the spoor being followed. While the tracker may benefit from superimposed spoor, too many proximate signs may sometimes make tracking more difficult, since the spoor being followed may be confused with similar proximal signs.

The art of tracking involves each and every sign of animal presence that can be found in nature, including scent, feeding signs, urine, faeces, saliva, pellets, territorial signs, paths and shelters, vocal and other auditory signs, visual signs, incidental signs, circumstantial signs and skeletal signs. Tracks are not confined to living creatures. Leaves and twigs rolling in the wind, long grass sweeping the ground or dislodged stones rolling down a steep slope leaves their distinctive signs.

Peripheral Perception

!Xõ hunters maintain that if, while they are hunting, they feel a "burning sensation" in the middle of their foreheads, just above the eyes, then they know that their quarry is just ahead of them. Some hunters say that this feeling on their foreheads is accompanied by perspiring under the arms. They also claim that they can sometimes "feel" the near presence of their quarry in this way even before they find its tracks. One could argue that, when hunters are tracking an animal, they analyse the complexity of signs, make an intuitive estimate of the age of the tracks within a specific context and then intuitively know that the animal may be just ahead of them. This intense concentration may give rise to the experience of a "burning sensation" on the forehead and the perspiration under the arms.

We are constantly bombarded by a multitude of stimuli to which we cannot attend. By selective attention our brains are able to select those stimuli that are relevant, while ignoring others. By means of peripheral perception we are also able to register stimuli that we do not know we perceive (Atkinson, Atkinson and Hilgard, 1981).

Even before the hunter consciously sees the animal's tracks, he may subconsciously perceive subtle signs of the animal's presence, such as the distant twittering of ox-peckers or barely perceptible scent of the animal, lingering in the air. The hunter may be able to perceive signs of an animal selectively and subconsciously, and his perception may find expression as intuitive feelings.

!Xõ hunters can apparently also "feel" danger, such as the presence of a leopard or a lion. One hunter described the experience in graphic detail, acting out his feelings and reactions. First he would feel his hair standing on end at the back of his head, after which his heart would start beating "wildly." His whole body would then go cold with fear. Sometimes, after feeling this sensation, he might have noticed a small bird acting strangely, which would have indicated the presence of a leopard or a lion hidden from view.

I have observed trackers "feel" danger by means of peripheral perception. While evaluating Joseph Mabunda in the Thornybush Nature Reserve for his Senior Tracker certificate, we were tracking a group of lions through thick bush. It was already mid-day and it was very likely that the lions could be lying up in the thicket, so we were alert for signs of their presence. I was attracted by a flicking movement in the thick bush and saw the lions a few moments before Joseph did. The lion flicks its ears to keep the flies away, and the frequency of the flicking movement is very distinctive – when a lion lies hidden in thick bush the only sign of its presence may the flicking movement of its ears and the swishing movement of its tail. I saw Joseph stop and freeze… for a few moments he scanned the bush and then pointed at the lions. It was clear that he became aware of the lions before he actually saw them. Afterwards he told me that he felt the cringing sensation of his hair on the back of his head moments before he saw the lions – he intuitively "felt" danger. He probably subconsciously perceived the flicking movement of the lion's ears by means of peripheral perception before he consciously saw the lions.

When "feeling" danger, the tracker may have registered signs of danger (such as a little bird acting strangely or the flicking of a lion's ears) by means of peripheral perception, without knowing it. Then he may have felt intuitively that something was wrong. This could have led to a sensation of fear, which in turn may have alerted him to the presence of the little bird or flicking ears, thereby corroborating his first impressions.

Intuition

Our conscious, explicit mind is deliberate, sequential and rational and it requires effort. Our intuitive mind is fast, automatic, effortless, associative, implicit (not available to introspection) and often emotionally charged. Humans have evolved mental shortcuts which enable efficient, snap judgments. Intuitions come from learned associations, which automatically surface as feelings that guide our judgments. But while intuition is powerful, it can sometimes be completely wrong, especially when we overfeel and underthink. Intuition needs to be checked against reality (Myers, 2007).

Intuition may be defined as reaching a conclusion on the basis of less explicit information than is ordinarily required to reach that conclusion. It usually occurs in situations where there is not enough time to appraise certain data, where the data are too complex for normal inferential processes, where the relevant data are heavily confounded with irrelevant data, and when data are exceedingly limited. Intuition is an inferential process in which some of the premises are contained in the stimulus event and some of them in the coding system of the perceiver, so the conclusions may go beyond the information given (Westcott, 1968).

When a conclusion is reached intuitively, the thinker usually does not know how he/she reached the conclusion. A great variety of cues may be used may be used for reaching a conclusion, without the individual having any idea of what the cues are or how they are being used. Some elements of the intuitive process may be conscious, while associative links may be made unconsciously. Information may be derived from diverse and complex contexts, and may be gained incidentally, peripherally or perhaps subliminally. Although the individual may not know how a conclusion is reached, intuition is primarily based on information received from the environment through normal sensory channels and acted upon by usual cognitive manipulations. Intuition differs from normal inference only in the sense that the individual is unaware of the process involved. Such a definition of intuition may include creativity, but intuition may not always be creative. Intuitive conclusions are not necessarily novel or unusual (Westcott, 1968).

The art of tracking involves many situations in which intuitive conclusions must be made. In difficult tracking conditions where signs may be sparse, where signs have very little information content and where a multitude of proximate signs may confuse the tracker, the interpretation of tracks and signs may be largely intuitive. Subtle variations in footprints that indicate the sex, size, age and the condition of the animals may not be well defined, and can only be determined intuitively, especially in conditions where footprints are not clear. In loose sand, for instance, tracks may have lost definition as the grains of sand slid together and as the wind gradually eroded the edges. On hard ground only fractions of footprints may be discernible. In such conditions the tracker must intuitively visualize what the track looked like before it lost definition. Similarly a large number of complex variables must be taken into account to estimate the age of tracks so the tracker's estimate may at best be intuitive.

During the course of tracking, a tracker is constantly taking in a multitude of signs. On the basis of track information gathered over a period of time a tracker may be able to intuitively predict the success of a hunt. Such an intuitive prediction may be revealed in the form of "feelings" or presentiments. In the process of tracking down an animal, or even before an animal's tracks have been encountered, a tracker may "feel" the near presence of their quarry by means of peripheral perception. The tracker may, on the basis of a complexity of signs, some of which may have been subconsciously perceived, intuitively know that the animal may be near. Trackers may also intuitively "feel" danger by means of peripheral perception (see above).

While it is clear that intuition plays an important role in tracking, and therefore in hunting, it also plays an important role in other spheres of hunter-gatherer societies. In their social relationships, for example, the sensitivity of G/wi men and women to each other cannot be appreciated by people living in urban situations, where perceptions of others have been blunted by fragmented and shallow relationships (Silberbauer, 1981). Modern societies in general, and education in particular, does more to stifle than to encourage intuitive thinking. It is usually the more independent and less socialized individuals who are more likely to be intuitive thinkers (Westcott, 1968). It may well be that the more independent and less socialized individuals are more intuitive because they are less inclined to be stifled by society. If modern society and education were less stifling, perhaps more people would be more intuitive. This may well be the case in hunter-gatherer societies, where intuition plays an important role not only in tracking, but also in social relations.

Interpretation of Activities

Apart from identifying animal tracks and being able to follow a trail, trackers must also be able to interpret the animal's activities so that they can anticipate and predict its movements.

These include when an animal has been lying down, that the animal was standing still, moving slowly or fast. The length of the stride indicates the speed of the animal, while the positions of the tracks relative to each other reflect the animal's gait, whether walking, trotting, galloping, bounding, jumping or hopping. Apart from specific gaits, the various actions of the animal may also be indicated by the tracks. Signs of digging or feeding of specific animals may not only indicate what they were feeding on, but also how they were feeding.

To interpret activities, the tracker must visualize the actions of the feet that created the various disturbances of the ground in and around the track. Signs that the animal's feet pushed into the ground may indicate a sudden stop or change of direction. Sand may be kicked up, indicating a fast gait. Drag marks may indicate fatigue or injury. Virtually all conceivable actions leave distinctive markings which may make it possible for the tracker to reconstruct the animal's activities.

Ageing of Tracks & Signs

One of the most difficult aspects of spoor interpretation is determining the age of spoor. Only very experienced trackers can determine the age of tracks with reasonable accuracy, while absolute accuracy is usually not possible. And while some trackers seem to be as good as good as one could expect them to be, others do not seem to be very good at all. Due to the complexity of the variables involved, estimates are usually at best intuitive. Tracker's estimates are usually more accurate for fresher footprints, becoming less accurate for older tracks, with a higher error for windy conditions (see Liebenberg, 1990a page 77).

While intuitive estimates based on weathering processes may not always be very accurate, a tracker can sometimes make more accurate estimations. Signs that involve rapid moisture loss may give a fairly accurate indication of the age of the spoor when it is still very fresh, such as droppings that are still slimy or sticky, or fresh urine. Saliva on bushes where an animal was feeding also indicates that the trail is very fresh. When an animal has been drinking at a waterhole, splash marks will be very fresh, since the water evaporates quickly. If it is still early in the morning, and the animal's footprints are superimposed on top of fresh tracks of a diurnal animal, such as a small bird, then there is a reliable upper limit to the age of the tracks. If the animal was resting in the shade, a fairly accurate estimation of the position of the sun at that time can be made. When a very strong wind is blowing, tracks may rapidly lose definition, so clear, distinct footprints will be very fresh.

When tracking down an animal, a high degree of accuracy is not important in determining the age of older tracks. All that is important for the trackers to know at this stage is whether or not they have a reasonable chance of overtaking the animal. A positive lead may be better than nothing, and a trail may be abandoned to take up a fresher trail, indicated by tracks superimposed on top of the tracks being followed. During the hunt trackers will continually re-evaluate the age of the tracks so that even if they are sometimes way off the mark, their estimates will on average become better and better as they close in on their quarry. It is crucial to know when the trail is very fresh since trackers must move stealthily when they are close to the animal. Each time that the hunters I accompanied indicated that the tracks were very fresh, it was not long before the animal was spotted a short distance away. In the art of tracking approximate estimates are sufficient to serve their purpose. Greater accuracy is not required, since hunters can make allowance for possible errors.

Reconstruction of Activities

To reconstruct an animal's activities, specific actions and movements must be seen in the context of the animal's whole environment at specific times and places. Where an animal is moving at a steady pace in a specific direction, or following the easiest route along a well defined path, and it is known that there is a waterhole ahead, it may be predicted that the animal is going to the waterhole. A browsing antelope will be moving slowly from bush to bush, usually in an upwind direction, so a tracker who knows its favorite food will be able to anticipate the next bush the antelope will go to.

While tracking down a solitary wildebeest spoor of the previous evening, !Nam!kabe pointed out evidence of trampling which indicated that the animal had slept at that spot. He explained consequently that the spoor leaving the sleeping place had been made early that morning and was therefore relatively fresh. The spoor then followed a straight course, indicating that the animal was on its way to a specific destination. After a while, !Nam!kabe started to investigate several sets of footprints in a particular area. He pointed out that these footprints all belonged to the same animal, but were made during previous days. He explained that that particular area was the feeding ground of that particular wildebeest. Since it was, by that time, about midday, it could be expected that the wildebeest may be resting in the shade in the near vicinity. He then followed up the fresh spoor, moving stealthily as the spoor became very fresh, until he spotted the animal in the shade of a tree, not very far from the area that he identified as its feeding ground. The interpretation of the spoor was based not on the evidence of the spoor alone, but also on his knowledge of the animal's behaviour, on the context of the spoor in the environment and on the time of the day. All this enabled him to create a reconstruction of the animal's activities which contained more information than was evident from the spoor itself. The ability to extrapolate from spoor evidence is important to predict the possible whereabouts of an animal.

The reconstructions of activities are always hypothetical and predictions could turn out to be wrong. For example, an antelope on its way to a waterhole may have scented the presence of lions and change direction to go to another waterhole. In this case, new evidence may be found, and the tracker may have to revise the initial hypothesis of where the animal was going.

Since tracks may be partly obliterated or difficult to see, they may only exhibit fractional evidence, so the reconstruction of these animals' activities will have to be based on creative hypotheses. To interpret the spoor, trackers must use their imagination to visualize what the animal was doing to create such markings. Such a reconstruction will contain more information than is evident from the spoor, and will therefore be partly factual and partly hypothetical. As new factual information is gathered in the process of tracking, hypotheses may have to be revised or substituted by better ones.

A detailed knowledge of an animal's habits, which may partly be based on hypothetical spoor interpretation, as well as knowledge of the environment, may enable trackers to extrapolate from incomplete evidence to recreate a complete account of the animal's activities. Spoor interpretation need not only be based on evidence from the spoor itself, but also on activities which may be indicated by the spoor in the context of the environment and in the light of the tracker's knowledge of the animal's behaviour. A hypothetical reconstruction of the animal's activities may enable trackers to anticipate and predict the animal's movements. These predictions provide ongoing testing of the hypotheses.

Track Anticipation and Prediction

In easy terrain trackers may follow a trail simply by looking for one sign after the other, but in difficult terrain this can become too time-consuming. Instead of looking for one sign at a time, the trackers place themselves in the position of their quarry in order to anticipate the route it may have taken. They then decide in advance where they can expect to find signs, instead of wasting time looking for them. Trackers may look for spoor in obvious places such as openings between bushes. In thick bushes they may look for the most accessible throughways. Where the spoor crosses an open clearing, they may look for access ways on the other side of the clearing. If the animal was feeding, and it is known what plants it prefers, then the tracker can look ahead for plant species where the animal will most likely have been feeding.

Animals usually make use of a network of paths to move from one locality to another. If it is clear that an animal has been using a particular path, the path may simply be followed up to a point where it forks into two or more paths, or where the animal has left the path. Where one of several paths may have been used, the trackers must of course determine which path that specific animal used. This may not always be easy, since many animals may use the same paths.

Knowledge of the terrain and animal behaviour allows trackers to save valuable time by predicting the animal's movements. To be able to predict the movements of an animal, trackers must know the animal and its environment to such an extent that they can identify themselves with the animal. They must be able to visualize how the animal was moving around, and place themselves in its position.

While foraging a porcupine may move in a zig-zag route, searching for food. When moving back to its den, it will follow a more-or-less straight course. As you get closer to the den, you may encounter old spoor of the same porcupine from previous days. Following the general direction, trackers can home in on the den site by following either the fresh spoor or any of the older spoor pointing in the same general direction. On hard, stony ground tracks may be virtually impossible to discern. Experienced trackers are able to anticipate more or less where the animal was going and will not waste time in one spot looking for signs, but will rather look further ahead.

Interpretation of spoor on recent outings may also enable the hunters to identify favoured feeding grounds and resting places. These may be indicated by the signs of animals visiting the same place repeatedly. On each outing the trackers will systematically take note of all signs of animal movement, identifying all spoor and making an estimate of the animal's size, sex, the age of the spoor, where it came from, how fast it was moving and where it was going. All information on recent animal movements, gained from their own as well as other's observations, will be taken into account when predicting the whereabouts of the most favoured quarry. They will also take note of tracks that they may not follow up immediately, but which may be followed up in future. For example, they may find the tracks of a large eland, but the spoor may be too old. They will note the direction of travel and age of the spoor, and will look out for it in case they find fresh spoor of that particular eland.

Since signs may be fractional or partly obliterated, it is not always possible to make a complete reconstruction of the animal's movements and activities based on spoor evidence alone. Trackers may therefore have to create a working hypothesis in which spoor evidence is supplemented with hypothetical assumptions based not only on their knowledge of the animal's behaviour, but also on their own creative ability to solve new problems and discover new information. The working hypothesis may be a reconstruction of what the animal was doing, how fast it was moving, when it was there, where it was going to and where it might be at that time. Such a working hypothesis may enable the trackers to predict the animal's movements. As new information is gathered, they may have to revise their working hypothesis, creating a better reconstruction of the animal's activities. Anticipating and predicting an animal's movements, therefore, involves a continuous process of problem-solving, creating new hypotheses and discovering new information.

The interpretation of an animal's activities and prediction of its movements is based not only on spoor evidence alone, but also on a knowledge of the animal's behaviour and the environment. The gait of the animal is indicated by the relative positions of the footprints. The speed at which the animal is moving is indicated by the distances between the footprints, as well as the way the sand is kicked up. The way the animal moves may further imply activities not evident in the spoor itself. If, for example, the footprints of a fox indicate that it was moving very slowly, this may imply that is was hunting for mice, lizards, scorpions and insects, and that it was moving slowly so as not to be seen while scenting for its prey. The hunting activity itself is not evident from the spoor, unless signs of a catch are found, but is indicated by the way the fox moves when hunting. It should be noted that the signs of the fox moving very slowly do not necessarily imply that is *was* hunting, only that it *may* have been hunting, since it could have been moving slowly for a different reason. Signs of a kill, however, would confirm that it was in fact hunting.

Karel Kleinman, a master tracker who worked as a ranger in the Kalahari Gemsbok National Park, pointed at some lion tracks going up the side of a dune. Immediately he could see that this male lion got up, ran up the dune at a trot, stood still to listen to something in the distance, and then trotted off at a steady pace in a specific direction. He explained that the lion had heard a female in the distance, got up and trotted higher up on the dune where he stood still to listen, and then trotted off to go and find the female. He then got into the vehicle and drove around some high dunes to find his way to where he predicted the lion had been going. He picked up the tracks and followed them to a spot where the lion had encountered two other lions, a male and a female. The tracks indicated that the two males had been fighting over the female, after which one of the males went off together with the female. The original set of tracks only indicated a male lion that got up, stopped, and continued at a trot. But the way it moved showed that it was not hunting, since it was not trying to move stealthily to stalk a prey animal. Rather, it stopped to listen to something at a distance that it found attractive, and then moved off at a steady pace. The way it moved indicated that it was attracted to a female in the distance.

Systematic and Speculative Tracking

Two fundamentally different types of tracking may be distinguished, namely systematic tracking on the one hand, and speculative tracking on the other. Systematic tracking involves the systematic gathering of information from signs, until it provides a detailed indication of what the animal was doing and where it was going. In order to reconstruct the animal's activities, the emphasis is primarily on gathering empirical evidence in the form of spoor and other signs. Speculative tracking involves the creation of a working hypothesis on the basis of initial interpretation of signs, knowledge of the animal's behaviour and knowledge of the terrain. With a hypothetical reconstruction of the animal's activities in mind, trackers then look for signs where they expect to find them. The emphasis is primarily on speculation, looking for signs only to confirm or refute their expectations. When their expectations are confirmed, their hypothetical reconstructions are reinforced. When their expectations prove to be incorrect, they must revise their working hypotheses and investigate other alternatives.

In systematic tracking, trackers do not go beyond the evidence of signs and they do not conjecture possibilities which they have not experienced before. Their anticipation and prediction of the spoor are based on repeated experience of similar situations and therefore they do not predict anything new. Even when a prediction is based on experience, however, it may not necessarily be correct in that particular instance. Systematic tracking is essentially based on inductive-deductive reasoning (Chapter 8).

In speculative tracking the trackers go beyond the evidence of signs. Anticipation and prediction are based on imaginative preconceptions. They conjecture possibilities which are either confirmed or refuted. Even when their expectations are confirmed, however, this does not imply that their hypotheses are correct, since they may still prove to be incorrect. When their expectations prove to be incorrect, a process of negative feedback takes place, in which they modify their working hypotheses to correspond with new spoor evidence. Speculative tracking involves a continuous process of conjecture and refutation and is based on hypothetico-deductive reasoning (Chapter 8).

Speculative tracking is a self-correcting cybernetic process, involving both positive and negative feedback. When signs confirm expectations, positive feedback reinforces the belief that you are on the right track. When it is clear that there are no tracks in an area where tracks would have been visible, negative feedback indicates that you have veered off the trail and need to correct yourself. However, you can also get false positive feedback if you incorrectly interpret a sign as positive feedback when in fact the sign was made by another animal. In this case you will stray further off the trail. Or you can get false negative feedback when crossing hard ground where there are no tracks visible. You may mistakenly conclude that the animal did not go that way, when in fact it did go that way but the ground is too hard to leave visible signs. In this case you may waste valuable time searching for the tracks elsewhere.

Systematic tracking involves a cautious approach. Since the trackers do not go beyond direct evidence, the chances of losing the spoor are small.

Even anticipation and prediction do not involve great risk of losing the spoor, since they are based on repeated experience. Provided the trackers can progress fast enough, they will eventually overtake their quarry. While systematic tracking may be very efficient in relatively easy terrain, it may prove to be very time-consuming in difficult terrain.

Speculative tracking, on the other hand, requires a bold approach. Anticipating the animal's movements, by looking at the terrain ahead and identifying themselves with the animal on the basis of their knowledge of the animal's behaviour, trackers may follow an imaginary route, saving much time by only looking for signs where they expect to find them. Trackers may visualize animals moving through the landscape and ask themselves what they would do if they were the animals, and where they would have gone. The tracker creates an internal simulation of different possibilities, thereby simulating and predicting the future. By predicting where animals may have been going, the trackers can leave the spoor, take a short cut, and look for the spoor further ahead. While speculative tracking may save much time, thereby increasing the chances of overtaking the animal, it nevertheless involves a much greater risk of losing the spoor and much time may be wasted in finding it again. Alternatively, systematic tracking may prove to be so time-consuming in difficult terrain, that it may be more efficient to risk losing the spoor occasionally for the time that can be saved by speculative tracking.

When learning to track, most beginners tend to be very systematic and to look for tracks in front of them on the ground. On the other hand, speculative tracking requires a lot of experience. So most trackers start off as systematic trackers and only become speculative trackers once they have mastered the basic skills. In the beginning it is also easier to gain experience through systematic tracking. As the learner gains more experience, the increase in knowledge should make it easier to do speculative tracking. However, making the transition from systematic to speculative tracking can be very difficult. The two methods are so fundamentally different that many trackers struggle to make the transition.

And the longer they only do systematic tracking, the more difficult it will become to make the transition.

In principle, there is a fundamental difference between systematic and speculative tracking. In practice, however, they are complementary, and a tracker may apply both types of tracking, so that there may not always be a clear distinction between the two. Ideally, a tracker should know to what extent either systematic or speculative tracking, or a combination of both, would be most efficient in particular circumstances. In very easy terrain, such as open, sparsely vegetated, sandy terrain, systematic tracking may be so quick that it may not be worth risking losing the spoor by speculation. In very difficult terrain, such as very hard, rocky terrain, a tracker may not get very far with systematic tracking, so that speculative tracking may be the only way to overtake the quarry. In open, flat terrain it may be difficult to anticipate an animal's movements, so systematic tracking may be more efficient. In thick woodland, where paths may be formed through gaps in the bush, or in hilly terrain where paths are formed by the contours, speculative tracking may be more efficient. Trackers may also alternate between systematic and speculative tracking as the terrain and vegetation changes during the course of tracking an animal. Usually tracking conditions will vary between conditions that favour either systematic or speculative tracking, requiring an optimal combination of both types of tracking.

Systematic tracking is more appropriate when tracking small species, such as the Grysbok, which have a small home range and which may circle back over its own spoor many times within its home range. In the rainy season, when the sand is wet and spoor may remain fresh looking for several days, fresh tracks could be confused with old tracks, making it difficult to do speculative tracking. When tracking a calf of an antelope, systematic tracking is also more efficient. Calves at a certain age, when their mothers hide them in thickets, tend to run around in circles, crossing back over their tracks many times in a small area. To find a calf therefore requires extremely systematic tracking. On the other hand, when tracking large animals that cover large distances, speculative tracking may be more efficient.

Speculative tracking becomes more efficient when an experienced tracker knows a particular area very well. A detailed knowledge of the terrain and a detailed knowledge of the animals found in the area, makes it easier to conduct speculative tracking. Trackers may also get to know individual animals and their particular habits, making it possible to predict where they will most likely be found. On the other hand, even expert trackers may not be able to do speculative tracking in an area they do not know and with species they are not familiar with. When working in an area they are not familiar with, even experienced speculative trackers may find it easier to do systematic tracking.

Speculative tracking is also important when tracking dangerous animals or dangerous criminals (Liebenberg, 2009). When tracking a lion, a rhino or dangerous criminals you cannot look at the ground in front of you, systematically following the trail. Your first priority is to look ahead for signs of danger. Secondly you look ahead to anticipate and predict where the animal was going. And only then do you look for tracks to confirm your predictions.

While systematic and speculative tracking are two complementary types of tracking, individual trackers may, under the same circumstances, tend to be either more systematic or more speculative. When dealing with sparse spoor evidence, the interpretation of individual trackers may differ considerably. A group of !Xõ trackers, for example, gave different interpretations of dried-out droppings from a large antelope in a pan after the footprints had been obliterated completely by the wind. One tracker, Kayate, identified it as being that of a gemsbok, while another, !Nam!kabe, maintained that is was that of a hartebeest. A third tracker, Boroh//xao, supported Kayate’s interpretation while a fourth tracker, !Nate, supported !Nam!kabe’s interpretation, so they could not reach consensus on it. At the time I did not have enough experience to know who was correct or if it was in fact possible under the circumstances to tell whether the already dried-out droppings, in the absence of footprints, could be identified as being either that of a gemsbok or hartebeest, so this point remains unresolved. Kayate then said that the antelope licked for salt, but that he did not know in which direction it went because he could not see the spoor. !Nam!kabe, however, had a more creative approach. He proposed that the antelope came from the east and went off to the west to its feeding ground. He went on to say that it did not come back that morning, but went to another pan. From that pan it would have gone in the other direction to where the grass is green. Although the only sign of the animal was its dropping, the identity of which was disputed, he reconstructed the animal's movements on the basis of the estimated age of the droppings, the direction the wind was blowing at the time it was deposited, the fact that the antelope usually move into the wind (to scent danger from ahead), its daily feeding and salt-licking habits and his knowledge of the environment. His hypothetical reconstruction went beyond the direct evidence of the signs, but enabled him to make a prediction which, if followed up, would either be confirmed or refuted. Sometimes his speculative predictions may have been refuted, but sometimes they may have been correct, and when they were, it would have given him a better chance of locating the animal than the more conservative systematic tracker, who would have no lead at all. While sparse spoor evidence will be of no use to the conservative, systematic tracker, who does not go beyond direct evidence, the more creative, speculative tracker may make bold conjectures, enabling him to predict where the animal may have gone. This ability would give the speculative tracker a considerable advantage in difficult terrain, where footprints are not always clear. The ability to solve problems in an imaginative way would also enable the speculative tracker to learn more about animal behaviour from tracks. Scientific progress is determined primarily by human creative imagination and not by the trial-and-error accumulation of facts (Lakatos, 1978a).

The difference in approach by individual trackers may be the product of different types of scientific minds. Modern scientists may broadly be divided into two types: systematic and speculative (Beveridge, 1950). This classification is arbitrary, however, since the majority of scientists probably fall somewhere between the two extremes, combining characteristics of both types. The systematic scientist work by gradual, systematic steps, accumulating data until a generalization is obvious. Discovery of new facts is achieved through patient and manual dexterity. Although systematic scientists may have a high intelligence which enables them to classify, reason and deduce, they may not have much creative originality. In contrast, speculative scientists create a hypothesis first or early in the investigation, and then test it by experiment. Making bold guesses they work largely by intuition, go beyond generalization of observed facts, and only then call on logic and reason to confirm the findings. While speculative scientists may be highly creative, they may not be storehouses of knowledge and may not necessarily be highly intelligent in the usual sense. Systematic and speculative types of minds represent extremes and most scientists probably combine some characteristics of both. Both types of scientists are necessary, for they tend to have complementary roles in the advancement of science.

The way systematic and speculative trackers acquire new knowledge may be analogous to the way modern scientists do. Systematic trackers may develop their scientific knowledge by systematically accumulating empirical data based on spoor evidence and direct observation of animal behaviour. Speculative trackers may develop their scientific knowledge by first creating hypotheses and then looking for spoor evidence to support their theory. Though some trackers may be inclined to be more systematic and others more speculative, most trackers would probably combine characteristics of both, varying from one extreme to the other.

In the hunting process systematic and speculative trackers may complement one another. When hunting in teams of two or more trackers, systematic and speculative trackers may be in constant dialogue, so that some form of consensus is reached. Such a consensus may represent an optimal combination of the two extremes, but trackers do not always agree on their interpretations of spoor or the best strategy to adopt.

Systematic and speculative trackers may also have complementary roles in advancing and maintaining the shared pool of scientific knowledge of a hunter-gatherer band or alliance of bands. Systematic trackers, on the one hand, may be able to accumulate and retain more knowledge, including knowledge gained from others. Speculative trackers, on the other hand, may be creative innovators, developing new knowledge, especially in changing circumstances, or rediscovering knowledge that may have been lost.

Knowledge of Animal Behaviour

The /Gwi, !Xõ and Ju/'hoansi knowledge of animal behavior essentially has an anthropomorphic nature. Animal behavior is perceived as rational and directed by motives based on values (or the negation of those values) that are either held by hunter-gatherers themselves or by other peoples known to them. These motivational and value system of animals do not correspond in all aspects with human systems, but are modified to fit the perceived circumstances of the animals themselves (Silberbauer, 1981; Heinz, 1978a; Blurton Jones and Konner, 1976).

Despite its anthropomorphic nature, their knowledge of animal behavior is sufficiently accurate for planning hunting tactics and for anticipating and predicting the activities of animals. Although their knowledge is at variance with that of European ethologists, it has withstood the vigorous empirical testing imposed by its use, illustrating the view that alternative cognitive maps can, up to a certain level of analysis, serve as equally effective equivalents (Silberbauer, 1981). The anthropomorphic nature of their knowledge of animal behavior is not necessarily unscientific. It may, on the contrary, be a result of the creative scientific process itself. Anthropomorphism may well have its origins in the way trackers must identify themselves with an animal. When tracking, they must think in terms of what they would have done if they had been the animal in order to anticipate and predict its movements.

The behavior of animals is seen by the /Gwi as bound by the natural order of N!adima (God). Such behavior can be accounted for in terms of knowable regularities, and is believed to be rational and directed by intelligence. Each species is perceived to have characteristic behavior, which is governed by its *kxodzi* (customs), and each has its particular *kxwisa* (speech, language). Animals are believed to have acquired special capabilities by means of rational thought. These capabilities are believed to have been passed on by the discoverers or inventors in that population, and were thereby institutionalized as elements of the species' customs (Silberbauer, 1981).

Mutually beneficial species and even some that are hostile to one another are believed to be able to understand one another's language, and some animals are believed to be able to understand a certain amount of /Gwi. A limited amount of the language of some species, such as the alarm calls of birds, can also be understood by humans (Silberbauer, 1981).

It has long been assumed by modern scientists that animals cannot communicate by means of symbolic expression as humans do. It was thought that while humans use arbitrary sounds (words) to represent abstract concepts, animals can only express emotion. Research suggests, however, that the sophistication of animal language has been underestimated. It has been found, for example, that vervets have different alarm calls for their three main predators, namely leopards, eagles and snakes. Other vervets react to each type of call in the appropriate way, each type of predator requiring different evasive action. This implies that vervets could be using symbolic language in which specific concepts or objects are represented by arbitrary sounds. Furthermore, it was found that calls that were perceived by monkeys as being different, each with a different meaning, could not always be differentiated by the human ear. It is therefore likely that humans would underestimate the extent to which animals are using signals to convey information. Evidence also indicates that the appropriate use of various alarm calls is learnt. Japanese macaques living in different areas have been found to use local dialects, suggesting that they have been culturally transmitted rather than genetically inherited (Dunbar, 1985).

!Xõ hunters also maintain that birds may warn them of danger, such as snakes, leopards or lions. Warnings are not only in the form of alarm calls, but may be transmitted by displays or other behavior. For example, a little bird may act strangely in a bush, indicating possible danger hidden from view or a courser may swoop down at something, indicating the presence of a leopard or a lion.

Many bird species produce characteristic calls which vary from "general purpose" distress calls to special alarm calls given in response to specific predators. Mobbing involves deliberate predator harassment by prey species. In birds, mobbing attacks are often associated with characteristic calls, which are unlike alarm calls. Mobbing may have a deterrent effect on a predator in that it may indicate to the predator that it has been spotted. It may also facilitate the cultural transmission of predator recognition (Barnard, 1983).

The trackers' ability to interpret spoor enables them to reconstruct the context of a particular animal's communication even when they could hear it, but not see it. By estimating the distance and direction of a call, trackers can go to the place where the animal was and study its tracks to determine what it was doing. So, for example, Kalahari hunters are able to interpret the nocturnal calls of jackals. When a jackal gives a long, smooth howl that diminishes in loudness (WHAaaa…), then it is simply maintaining contact with other jackals. If, on the other hand, it gives a shuddering howl, diminishing in loudness and ending in a soft cough (WHA-ha-ha-ha…umph), then it is following the spoor of a scavenger or a large predator. Kalahari trackers explain that it "stutters" because it is afraid. If the jackal gives the shuddering howl only once, then it was following a hyaena spoor. It has left the spoor after the first call because it will not get much meat by following the hyaena. If, however, it repeats the shuddering howl several times, then it is following the spoor of a leopard or a lion. It continues to follow the spoor because it knows that the spoor will lead to a lot of meat. Apart from warning the hunters of the danger of lions at night, jackal calls may indicate the recent movements of predators and scavengers, which may be taken into account when planning hunting strategy.

The /Gwi and !Xõ folk knowledge contains more information about ethology, anatomy and physiology of mammals than about other classes. Their concepts of mammalian ethology are also more overtly anthropomorphic than those concerning other classes (Silberbauer, 1981; Heinz, 1978a). Each of the large mammal species, which can be prey, a competitor for prey, or a danger, has a specific name. Many of the small mammals that are peripheral to the hunter's interest – such as rodents – are given generic terms or derived names. Their knowledge of antelopes is the most extensive of all animals. It includes information on their food habitat, habits, social behavior and reproduction.

When interpreting mammal behavior, anthropomorphic terms are used to describe individual animals. The prey animal is expected to do its best to avoid the hunters, using the strength and intelligence characteristic of its species. While the hunter expects to overcome the difficulties that challenge his own skill and cunning (such as the animal's behavior and other circumstances), there is always the possibility of being outwitted or otherwise frustrated by the individual animal's idiosyncratic behavior. Some animals are said to be ingenious in the ways they outwit the hunter. Others, who do not conform to the customs of the species, are said to be stupid. When studying a herd to select their target, hunters classify individual animals, using terms associated with human attributes of personality and character. Those animals that are judged to present too much difficulty because of their contrariness or courage are rejected. Some animals are cowardly or cheating. Others ore insolent or conceited and may therefore be likely targets. /Gwi hunters use more than 18 categories which provide the basis for predicting the animal's behavior before and after it has been shot. The /Gwi also project their own values and habits in explaining the social structure of groups and other types of mammal behavior (Silberbauer, 1981).

The extent of hunters' knowledge of animal behavior progressively declines in relation to mammals, birds, reptiles and amphibians, and is least in relation to invertebrates. The extent to which human characteristics are attributed to animals are also the greatest with mammals and the least with invertebrates (Silberbauer, 1981). Furthermore, hunters' interest in animal life is not limited to the animals they hunt, but appears to be in direct proportion to their potential relevance to tracking and the ability of hunters to distinguish their tracks. Every animal, down to the smallest invertebrate that leaves a characteristic track or trail is relevant to tracking. While hunters study animal behavior far beyond their immediate utilitarian needs in hunting, even the most obscure detail may be used at some point in the future to interpret tracks and signs. If, for example, the trail of a millipede or a particular mongoose species is superimposed on the track of the trackers' quarry, then that particular bit of information will only be useful to the trackers if they have a detailed knowledge of the daily habits of the animals in question.

Yet the relevance of animal behavior to tracking is limited to the trackers' ability to identify tracks. Insect species, for example, are difficult to identify by their tracks since many species have identical trails. The relevance of insect tracks is therefore confined to what all insects, which have similar trails, have in common. The same applies to the tracks of small rodents or small passerines. For example, hunters know that all passerines are diurnal, but that some mice are diurnal, while others are nocturnal. The tracks of mammals the size of mongooses and larger are all distinguishable, as well as those of large birds. It would appear that species whose tracks can be identified are all given specific names by hunters, while groups of species whose tracks are indistinguishable are given generic or derived names. Thus, although most doves have the same name, the Namaqua dove is given a distinct species name by the !Xõ and the /Gwi. When I showed my track illustrations of dove tracks to a group of !Xõ trackers, they were able to single out the tracks of a Namaqua dove.

Nevertheless, it is significant that trackers develop knowledge for the sake of knowledge that goes far beyond the practical needs of tracking and hunting (see below).

In order to put the hunters' knowledge of animal behavior into perspective, it must be understood from the tracker's point of view. As was noted earlier, in order to understand animals, the trackers must identify themselves with an animal. Yet in doing so they must inevitably project themselves into the animal. In tracking, signs are the basic form of information, and the trackers' knowledge of animal behavior is used to create a model in terms of which signs are interpreted.

Knowledge for the Sake of Knowledge

One of the characteristic qualities of the tracker is an innate curiosity about the smallest details in nature. Perhaps the most striking example of knowledge for the sake of knowledge among /Gwi trackers is found in their detailed knowledge of ants.

In general, invertebrate categories named by the /Gwi of the central Kalahari are those containing members that are useful (providing food, arrow poison, medicines, or some means of decoration), those that are dangerous (i.e. which sting, bite, exude irritant fluids, or are believed to be vectors of disease), those that are particularly striking in appearance, and those that are nuisances (Silberbauer, 1981). However, their knowledge of ants, for example, far exceeds these requirements. I interviewed Karoha, /Uase and !Nate of Lone Tree in the central Kalahari, Botswana. The ants were collected in the vicinity of one pan during one field trip.

The /Gwi have eleven names for ants, including the velvet ant (a wingless wasp), and termites. Phonetic spelling of the ant names are: ||om||om (including *Pheidole* sp., *Tetraponera* sp., *Camponotus* sp. 2 (*foraminosus* – group), and *Meranoplus* sp.), |xam (*Anoplolepis steingroeveri*, *Monomorium* sp., and *Pheidole* sp.), !ale (*Myrmicaria natalensis*), !gom (*Pachycondyla berthoudi* and *Plectroctena mandibularis*), !uje|e|e (*Ocymyrmex* sp.1 and *Ocymyrmex* sp.2), !ole (*Camponotus* sp. 1 (*mystaceus* – group)), |da (*Camponotus fulvopilosus*) and ||ha||hane (Mutillidae sp. 3); the velvet ant: |a|aana (Mutillidae sp. 1 and Mutillidae sp. 2); and the termites: |ham (termite specimen 8A, 8B, 9A, 9B) and ‡'aa (termite specimen 14A). In addition, they also distinguish between a small !gom, |are!gom (*Pachycondyla berthoudi*) and a big !gom, !uri!gom (*Plectroctena mandibularis*), where the 'small' and 'big' ants are clearly recognised as being different species. They also distinguish between |are!uje|e|e (*Ocymyrmex* sp.2) and !uri!uje|e|e (*Ocymyrmex* sp.1), as well as |are|ham (termite specimen 8A, 8B) and !uri|ham (termite specimen 9A, 9B). However, |are|xam (*Monomorium* sp. and *Pheidole* sp.) and !uri|xam (*Anoplolepis steingroeveri*) are regarded as the same species (see below). ||om||om is the generic name for all ants, including ants that do not have specific names. Some ants referred to by this name are clearly recognised as different species, and may be described as the 'small red ants' (*Pheidole* sp.), the 'small ants that live in trees' (*Tetraponera* sp.), or 'the red ant that bites you' (*Camponotus* sp. 2 (*foraminosus* – group)).

Some ant names are arbitrary and do not have any meaning, such as ||om||om, |xam, ‡'aa, |da and ||ha||hane. Other ant names describe a distinctive feature of the ant. !gom means 'to kneel', because when they sting, the poison is strong and acts quickly – it is so painful that one has to sit down on one's knees. |a|aana means 'your body shakes', because the poison is very strong. !uje|e|e means 'to carry all things back to their home', because they are both predators and scavengers – they scavenge the skeletal remains of millipedes, insects, dried out berries, as well as anything they can kill. !ale means 'to carry new things', because they are predators that feed on anything they can kill themselves. |ham means 'sticky', because they have soft bodies. !ole refers to the colour of the ant, a light reddish-orange. Some ants are edible. |da is described as the 'old people's rice', because it is a food reserved for old people. !ole is used as a 'salt' and is eaten with a plant food.

Much of their knowledge of ants is gained in a tracking context. This is illustrated by their detailed knowledge of the !uri|xam (*Anoplolepis steingroeveri*). In one instance we noticed that for quite a large distance there were no tracks of steenbok or duiker (small antelope). At one point I noticed large black ants were swarming all over the ground and biting the trackers on their feet. One tracker, !Nate, told me that this is why we have not seen any steenbok or duiker tracks in that area. The |xam ants persist in biting them, forcing them to avoid the area. A short distance further !Nate pointed at sign where a steenbok had been lying down, showing signs of agitation as it got up and turned around in circles, before eventually leaving the area. They further explained that during the rainy season (November to March) the |xam cut grass which they drag down their holes to store for the dry season. The |xam only eat grass and soft plants. During this period they do not want any other animals to come near their holes. If a steenbok comes too near, they become aggressive and bite it. When they bite an animal they cover the bite with a 'liquid from the abdomen.' They will attack steenbok, duiker, jackals, aardwolves, foxes, hares, springhares, mongooses and ground squirrels. The trackers further say that the springhare eats too much grass, which is why the ants attack them. They maintain that the aardvark does not eat the |xam ant.

They say that the aardvark feeds on |ham, !ale, |da and !uje|e|e. It does not feed on |xam, ‡'aa, !gom, |a|aana, ||om||om, !ole and ||ha||hane. The reason why it does not feed on the ‡'aa termite is because the nest is too deep underground and because its tongue is too thin to lick them up when they are above ground. They note that the aardwolf does not dig for ants like the aardvark. It only feeds on ‡'aa and !uje|e|e. Unlike the aardvark, it feeds on the ‡'aa termites when they are above the ground by licking them up with its broad tongue. The pangolin feeds on |ham, and not ‡'aa, for the same reasons as the aardvark.

While tracking an aardvark, they pointed out a termite mound broken by it. !uri|xam ants were carrying |ham termites from the broken mound back to their own nest. The trackers explained that the |xam do not kill the |ham, since they have seen the |ham alive in the |xam nest. Their theory is that the |xam change the |ham into eggs. These eggs then grow into |xam ants. As evidence of this they pointed to a hole in the ground into which the |xam were carrying the |ham. At the same time, other |xam were carrying eggs from the same hole to another hole nearby. Whether this theory is correct or not, it illustrates the way trackers create hypotheses to explain observed behaviour.

Another theory is that the |are|xam (*Monomorium* sp., and *Pheidole* sp.) and the !uri|xam (*Anoplolepis steingroeveri*) are the same species. They believe that the smaller |are|xam grows into the !uri|xam, i.e. the |are|xam are the 'babies' of the !uri|xam. Since *Anoplolepis steingroeveri* is polymorphic and the smaller ants are very similar in appearance, this is an understandable assumption. They maintain that the |are|xam have their own nest near that of the !uri|xam, and that the nests are linked with tunnels deep under ground. They say that if you dig down you will find both in the same nest, but it is very deep. Only when they reach a certain size, do the |are|xam move over into the nest of the !uri|xam.

These examples show a level of detail in their knowledge of ants that far exceed the practical requirements of hunting. In fact much of this knowledge may not be relevant to hunting at all. This demonstrates that /Gwi trackers develop knowledge for the sake of knowledge itself.

Mental Qualities

Within each age group there were a wide range of hunting abilities from modest to excellent. A study of Ju/'hoansi hunters showed that in the younger age groups, from 15 to 38 years old, 95 to 100 per cent of all the kudu kills were made by the better half of the hunters, while in the older age groups, from 39 to 49+ years old, 70 per cent of the kudu kills were made by the better half. Furthermore, in the younger age group, 70 per cent of all the kudu kills were made by only 17 per cent of the hunters, while almost half the hunters made no kills at all (Lee, 1979).

If above average eyesight or physical fitness were the main factors determining hunting success, one would expect the poorer half of hunters in a particular age group to contribute an even smaller percentage as they grow older. Hunting does not require exceptional physical fitness, and during the course of their normal activities hunters get enough regular walking exercise for any of them to be fit enough to hunt. Although one cannot track with poor eyesight, a tracker does not need exceptional eyesight. It is more important to know what to look for and where to look for it. Excellent eyesight may help in systematic tracking, but it will make no difference in speculative tracking. Skill in stalking and shooting are acquired at a relatively early age and do not improve with age. When a young man accompanies an old man, the young man will do the shooting.

The fact that the better half of hunters made most of the kudu kills may be explained by the hypothesis that tracking, which is intellectually the most demanding aspect of hunting kudu (since it is a woodland species that requires speculative tracking), requires above average scientific intellectual abilities. The difference between the age groups may be because younger trackers must rely more on their own creative abilities, while older trackers can rely more on knowledge gained through their own as well as other's experience. The poorer half of hunters in a particular age group can therefore contribute a larger percentage of the total number of kills as they gain experience with age.

Mental qualities listed by Ju/'hoansi hunters as essential in hunting include alertness (*chiho*), sense (*kxai≠n*), knowledge (*chi!ã*) and cleverness (*/xudi*) (Blurton Jones and Konner, 1976). The /Gwi use the word */xudi* for ingenuity, i.e. the ability to devise a novel and effective solution to a problem (Silberbauer, 1981). The art of tracking involves a process of creative problem-solving in which hypotheses are continually tested against track evidence, rejecting those which do not stand up and replacing them with better hypotheses. Intuition is important in dealing with complex variables, such as in estimating the age of tracks or interpreting tracks in loose sand. Concentration and memory also play a vital role in tracking.

In dealing with scientific knowledge, hunters were careful to discriminate objective data from theory and interpretation (Blurton Jones and Konner, 1976). Behaviour reconstructed from tracks was regarded with great confidence, but was distinguished from data based on direct observation. A distinction was also made between behaviour actually seen or reconstructed from tracks and behaviour that they thought might happen. While hunters admitted ignorance very readily, some might have given a hypothetical explanantion of a phenomenon that was not clearly understood. They also discriminated observed data from what they have heard someone else say they have seen and seem to expect skepticism of each other (Blurton Jones and Konner, 1976). Such skepticism is in fact the hallmark of scientific behaviour (Lakatos, 1978a).

Underlying Simplicity, Symmetry and Unity

While !Xõ and /Gwi trackers have no difficulty in recognizing differences in the tracks of different animals, not all of them can explain why they differ as they do. When asked, for example, why the track of a steenbok is different from that of a duiker, a standard answer would be: "Because that is how God made them." However, some trackers are able to give very good explanations, or hypotheses, of general characteristics of the tracks and the underlying similarities between different animals.

In 1985 one !Xõ tracker, Bahbah of Ngwatle Pan in Botswana, and in 2012 independently four !Xõ and /Gwi trackers, !Nate, /Uase, Karoha and Nxjouklau of Lone Tree in Botswana, provided essentially the same explanation. They pointed out that the tracks of steenbok, springbok and gemsbok are the same, i.e. the animals all have sharp, pointed hoofs, while the tracks of duiker, kudu and eland are the same, i.e. the animals all have rounded hoofs (Fig. 3, page 91). They also explained why some antelope have sharp, pointed hoofs while others have rounded hoofs. In order to escape danger, the steenbok, like the springbok, must run very fast over the open plains. (Steenbok and springbok are species which

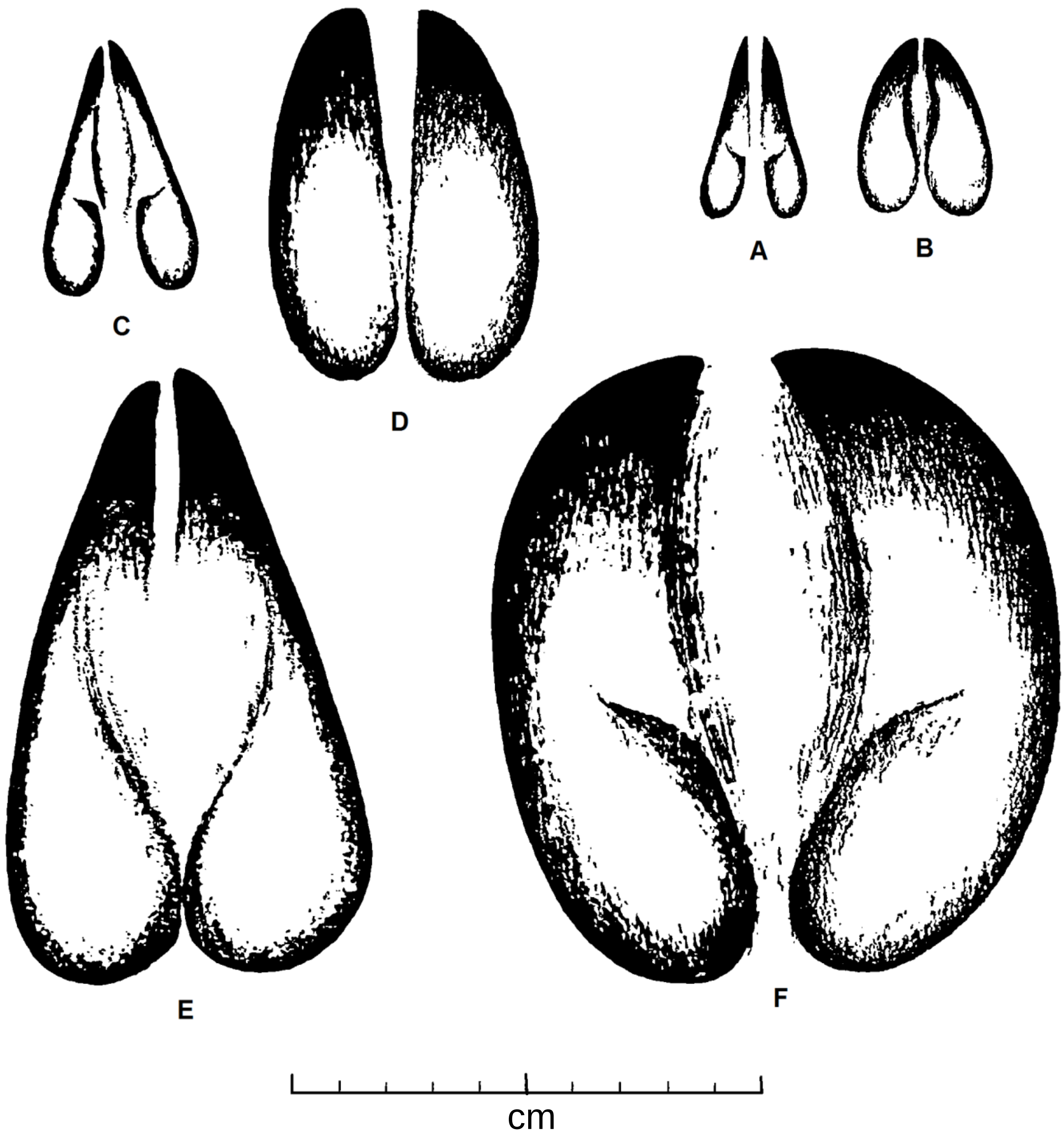


Fig. 3: The right fore tracks of (A) steenbok (B) duiker (C) springbok (D) kudu (E) gemsbok and (F) eland

inhabit open country). Their sharp, pointed hoofs tread deeply, pointing down into the sand, to obtain a good grip. The steenbok, they said, runs faster than the duiker, while the springbok runs faster than the kudu. The duiker and the kudu cannot run fast because they have heavy bodies, relative to their sizes. Their hoofs are more rounded for agility and they tread flat-footed to support their weight. They keep in thick bush and to escape danger, they run a zigzag course through the bushes and then hide themselves. (Duiker and kudu are woodland species and do not occur in open grassland). The duiker and kudu, they maintained, run "cunningly" to escape their enemies.

The hartebeest and wildebeest, which have broad, triangular tracks, are also the same. They run fast, but may run into open areas or bushes – they are different from the steenbok/springbok/gemsbok as well as the duiker/kudu/eland and therefore form a separate class.

The warthog, however, which have small, square tracks, is in a class of its own and not like any of the other groups. It's footprints are square, not like that of the duiker. It runs in a zig-zag way, not straight, but into bushes and underneath low branches. It has short legs (not long legs like the duiker), so it cannot jump over bushes and must therefore go underneath them.

This classification system for hoof shapes is an example of simplicity and symmetry in "law like" generalities that explain and unify different tracks at a deeper underlying level (See *Thematic Presuppostions*, Chapter 8).

The Scientific Process in Tracking

Since hunter-gatherers of the Kalahari no longer live a nomadic way of life, it is not possible to study the art of tracking in its original context. In particular, it is not known how trackers from different bands interacted and how new ideas were exchanged and shared by hunter-gatherer societies as a whole. Nevertheless, a hypothetical reconstruction of the art of tracking as a collective research programme of a community of interacting trackers may help to explain how science originated.

As Imre Lakatos (1978a) proposed, a scientific research programme consists of a developing series of theories. It has a tenacious "hard core" and a heuristic which includes a set of problem-solving techniques. A "protective belt" of auxiliary hypotheses, on the basis of which initial conditions are established, protects the "hard core" from refutations. Anomalies, which always occur, are not regarded as refutations of the "hard core," but of some hypothesis in the "protective belt." While the "hard core" remains intact, the "protective belt" is constantly modified, increased and complicated.

In considering the art of tracking as a scientific research programme, it is useful to distinguish three levels of research activity: firstly, each hunt may be regarded as a small scale "research programme"; secondly, each individual tracker may be seen to have his/her own "individual research programme"; and thirdly, a group of trackers who interact with one another may be seen to have a "collective research programme."

The public component of modern science, which consists of published papers, finished research reports and authoritative textbooks, mainly emphasizes the "collective" aspect of science, while the private aspects of the actual research of individual scientists remains hidden from public view. Although these private aspects are obviously of primary importance in the creative scientific process, they are often ignored in public discussions of science itself. The art of tracking, however, is much more individualistic than modern science, or at least the "public" side of modern science. The survival of hunters ultimately depends on the success of particular hunts, and the success of particular hunts depends on the tracking abilities of each individual tracker. To understand the art of tracking as a collective research programme, it is therefore necessary to consider it from the perspective of individual trackers and particular hunts.

Each particular hunt may be regarded as a small scale "research programme" (or perhaps a "search programme"), consisting of a series of problem-solving events. Every hunt is a new experience (or "experiment"), in which new problems may be encountered which may require new solutions, confirming or refuting previous hypotheses. The tracker sets out on a hunt on the assumption that the animal can be expected to act in accordance with a set of hypotheses. These hypotheses may constitute the "hard core" of his/her individual research programme. Once the hunt is in progress, new information may contradict the tracker's initial expectations, so auxiliary hypotheses may have to be summoned to explain the tracks and predict the animal's movements. As the hunt progresses and more and more information is gathered, initial working hypotheses that have been refuted may have to be revised and new hypotheses added so that the tracker can develop a better and more complete reconstruction of what the animal was doing and where it was going. As a hunter gains experience, each hunt may be seen as a continuation of previous hunts.

During the course of a hunter's experience, some hypotheses may be correct, while others may be wrong. If the tracker's correct hypotheses outweigh the wrong hypotheses, his/her individual research programme will become more successful. Such a tracker will therefore become more successful as a hunter. Conversely, if a tracker's hypotheses are more often wrong than right, he/she will not become more successful and may even become less successful. Interaction between trackers will ensure that the ideas of the most successful hunters will be adopted by the less successful hunters. Conversely, the views of the least successful hunters will be disregarded by others. The "collective research programme" of a band will therefore be increasingly successful rather than less successful, since the more successful hypotheses of the better hunters will supersede those of the less successful hunters.

In hunter-gatherer bands, the meat provided by successful hunters was shared with others, including unsuccessful hunters. Since hunters could depend on others for meat when they failed, they had the freedom to be wrong at times. The principle of sharing therefore gave trackers a degree of "academic freedom" to explore new ideas. The success or failure of new ideas, i.e. the predictive value of new ideas, would determine whether they would be taken up into the collective research programme of a band.

Thus the art of tracking, within the original context of hunter-gatherer subsistence, would have been a science with a high degree of individual freedom and flexibility. It would also have been subject to a process of "natural selection," since the success of the tracker's ideas would have determined the success of the hunt, upon which the survival of the band ultimately depended. It was not crucial that all hunters in a band were highly successful trackers, and there would have been some room for some trackers to have less successful research programmes. But the survival of the band would have depended on the existence of at least a reasonable number of trackers with successful research programmes. While some hunters may have had limited success at times, the most successful trackers would have determined the success of the collective research programme. The "hard core" of the collective research programme consisting of a number of well established hypotheses or theories, would have been transmitted by means of oral tradition, while a "protective belt" of auxiliary hypotheses would have been constantly modified and adapted.

As Karl Popper (1963) pointed out, tradition has a fundamental role in science. The creation of traditions brings some order into the world we live in, thereby making it rationally predictable. Without tradition, knowledge would be impossible. The advance of knowledge consists in our modification of earlier knowledge, and everything about our traditional knowledge is open to critical examination. Tradition therefore have the important double function of not only creating some order, but also giving us something upon which we can operate, something that can be criticized and changed. Progress in science must proceed within the framework of scientific theories, some of which are criticized in the light of others.

The very nature of oral tradition may have made a continuous process of discovery a necessity. In time, knowledge may be forgotten and when someone dies a large amount of knowledge may be lost. In a small band, with only ten hunters, of whom only five may have been reasonable trackers, of whom only one or two may have been excellent trackers, it is unlikely that they could have remembered enough information to deal with every conceivable problem that could arise in tracking. The number of possible hypothetical connections that could be made between all the signs a tracker may encounter in a lifetime of hunting may well be infinite. At best, they may have been able to perpetuate through oral tradition the "hard core" of a collective research programme, while new auxiliary hypotheses would have had to be invented continuously to deal with new problems as they arose.

During times of extreme environmental change it is possible that even previously successful "research programmes" may have failed to adapt to changing circumstances. In such a case the band may have failed to survive. During times of extreme climate change, only the most creative trackers may have been able to adapt and develop successful "research programmes" within the context of the changing environment. Climate change would therefore have provided strong selective pressure for more creative trackers. As an ongoing research programme involving a continuous process of discovery, the art of tracking would have had a high degree of adaptability in changing circumstances.

A scientific research programme consists of a set of hypotheses that form a "hard core" which is protected from refutation by a "protective belt" of auxiliary hypotheses (Lakatos, 1978a). The art of tracking involves an ongoing process of problem-solving and often new hypotheses must be created to explain signs that cannot be explained in terms of the hunter's "hard core" hypotheses. When hunting with dogs, for example, hunters (who hunt on foot, not horseback) concentrate on gemsbok. Unlike other antelope which flee from dogs, gemsbok will usually stand and fight the dogs, giving the hunters the opportunity to kill it. This may be regarded as a "hard core" hypothesis upon which the hunter bases his initial assumptions when he hunts with dogs.

However, there are exceptions to the rule, which are explained in terms of auxiliary hypotheses. Firstly, although other antelope usually flee from dogs, a female will stand to protect her young. Secondly, not all gemsbok will stand and fight, and those that do, will not always do so. When a gemsbok is encountered in the open (which is usual), it will not stand and fight in the open, but will flee into a more wooded area where it can protect its rear by standing against a thick bush, while fighting off the dogs in front of it. As the gemsbok flee into more wooded areas, hunters can see from the way they run which will stand to fight the dogs and which will not stop. This is explained in terms of the animals' "personalities." Some gemsbok are said to be courageous, while others are more timid.

These hypotheses are used to create a model on which the hunter bases his strategy. When he encounters fresh gemsbok tracks, his initial strategy is based on the assumption that the gemsbok he is pursuing will stand and fight the dogs. Only after the gemsbok has reacted to the dogs will the hunter be able to predict if a specific gemsbok will stand or flee. Similarly, if the tracks of other antelope are encountered, it is assumed that they will flee, unless the tracks of a female with her young are found. These hypotheses may not always enable the hunter to predict the reactions of gemsbok. On one hunt, !Xõ hunters pursued a gemsbok into a wooded area. Although the signs all indicated that this particular gemsbok would stand and fight, it did not, leaving the hunters somewhat puzzled.

On their way back the hunters stopped to study fresh lion tracks close to where the gemsbok had passed. They pointed to signs indicating that two lions had been leaping at each other in play. The next morning, after sleeping on it, one hunter explained why the gemsbok did not stand and fight as they had expected it to. As the dogs chased it past that point, the gemsbok scented the fresh lion tracks, thought that it was being chased by lions, and carried on running.

To explain why the gemsbok did not react as expected, circumstantial evidence was used to create an additional auxiliary hypothesis. It should be noted that the presence of fresh lion tracks need not necessarily have related to the gemsbok's actions. It was only a *possible* hypothetical explanation. Yet it was not simply an *ad hoc* hypothesis, since it did have predictive value – it made a *novel prediction* about the behavior of the gemsbok in relation to fresh lion tracks. If the explanation was correct, then the hunter could have decided to avoid areas with fresh lion tracks in future, since the chances of success would have been diminished by its presence. By not wasting time on gemsbok that would not stop in any case, the hunter would have improved his chances of success. Conversely, if his hypothesis was incorrect, then potentially good leads would not have been followed up. Then the hunter's chances of success might have decreased, since he might not have taken advantage of tracks that could have led to success.

The predictive value of a hypothesis based on track interpretation, therefore, may either increase or decrease a hunter's chances of success. As tracking involves a continuous process of problem-solving, incorrect hypotheses may be refuted while hypotheses that consistently enable the tracker to make successful predictions will be retained.

As new information is gathered, the hunter's theories of animal behavior may become more and more sophisticated. New hypotheses are created to explain signs that may contradict his initial expectations, in order to make new predictions. Scientific knowledge is not gained by trial and error. Rather, novel facts are predicted by means of hypotheses that explain signs that would otherwise be meaningless. To return to the earlier example, if the hunter had not explained the gemsbok's behavior in terms of the presence of fresh lion tracks, the possible influence of fresh lion tracks on gemsbok would not have been known. Then the presence of the lion tracks would have been simply an incidental observation, with no meaningful value to the hunter.

Critical discussion is the basis of rational scientific enquiry (Popper, 1963). If two or more trackers are hunting together they will discuss the evidence of signs and debate the merits of various hypotheses. In the course of tracking an animal, hypotheses will be tested continually against the tracks, replacing those that are refuted by better ones. Although critical discussion does not always result in the correct consensus, most often the consensus is the correct interpretation, even if the correct interpretation may initially be a minority position.

Recently I started conducting formal evaluations of Kalahari trackers so that they can be awarded Tracker Certificates for potential employment opportunities (see Chapter 10). I discovered that even the most experienced trackers sometimes make surprising mistakes when they identify a track at a glance. But when two or three of them then have the opportunity to discuss the tracks, they invariably self-correct themselves and come up with the correct answer. I realized that some of the rare species, like cheetah, are hardly ever seen by hunters who move on foot, since these animals are not only very rare, but actively avoid being seen by hunters. Hunters rarely have the opportunity to see a cheetah and then study its tracks. To get to know their tracks they have to study its behaviour and then deduce which animal it is. For example, the cheetah runs down its prey, while the leopard stalks and pounces on its prey. Only when they find a kill site will they have the opportunity to study the animals's tracks, and from these few opportunities they must remember the details to identify the animal in future. So when you test them on an individual track in isolation, they may make a mistake at first glance. But after engaging in critical discussion, they will correct themselves and give the correct answer. Most significantly, when two trackers make the same mistake and a third tracker makes the correct identification, the consensus answer would be correct, even though the tracker who individually gave the correct answer was in the minority. This illustrates that even at the level of track identification, critical discussion plays an important role in tracking.

On one occasion, two !Xõ trackers, Kayate and !Nahm!abe, could not reach agreement on their interpretations of the tracks. Kayate, who was the dominant personality among the group of four hunters, managed to persuade the other two, !Nate and Boroh//xao, that he was right, and so his interpretation was accepted by consensus. Judging by my own interpretation of the tracks, however, I believed !Nahm!abe was correct. Apart from the fact that Kayate had a more dominant personality,

!Nahm!abe was a stutterer, which put him at a disadvantage. With all the click sounds in the !Xõ language, he often had great difficulty in putting across a convincing argument. Of the four hunters, !Nahm!abe was the most imaginative tracker, so his original ideas were often not accepted by the others. The other three often mocked him for "telling stories." Yet on the one hunt, after the other three had already given up hope, it was his insight and determination that resulted in the successful tracking down of a wildebeest. Scientists, contrary to the *belief* that they never knowingly depart from the truth, are always "telling stories" (Medawar, 1967).

Apart from their critical attitude, Kalahari trackers also show extensive curiosity. Direct observations are often embellished with an immense amount of detail. The evident delight with which they describe their observations suggests that hunters find such observations interesting for their own sake. They have a greater interest in animal behavior than is required for the practicalities of any specific hunt. They explore problems and acquire knowledge far beyond the utilitarian. The /Gwi, !Xõ and Ju/'hoansi appear to know more about many aspects of animals behavior than European scientists. A large store of information is accumulated and communicated, which may or may not turn out to be useful in hunting. This may well be of adaptive value, since knowledge that is gained when not needed, may be useful at another time (Blurton Jones and Konner, 1976; Heinz, 1978a; Silberbauer, 1981).

Science involves a continuous process of discovery. The /Gwi recognize fluctuations in the extent of their knowledge and of changes in the culture. They believe that much knowledge was lost in the smallpox epidemic of 1950 when many bands were decimated and dispersed. Since then, some of the old knowledge has been rediscovered, and new knowledge added. While recognizing the merits of known and tested solutions, they accept change and feel free to devise novel solutions to problems (Silberbauer, 1981).

Mythology and Religion

It is not possible to draw a clear distinction between the scientific knowledge and mythology of Kalahari hunter-gatherers. Superstition may well be an inadvertent nonadaptive by-product of scientific reasoning (see *Superstition and Irrational Beliefs*, Chapter 8). One of the more obvious ways is where non-rational beliefs form part of the body of scientific knowledge used to make predictions in the hunting context.

The /Gwi believe that some species possess knowledge that transcends that of humans. The Bateleur eagle (*Terathopius ecaudatus*) is believed to know when a hunter will be successful and will hover above him, thereby acting as an omen of sure success. Some steenbok (*Raphicerus campestris*) are thought to possess a magical means of protecting themselves from a hunter's arrows, while the duiker (*Sylvicapra grimmia*), is believed to practice sorcery against its animal enemies and even against conspecific rivals. Baboons, because of their legendary love of trickery and teasing, are believed to eavesdrop on hunters and to pass on their plans to the intended prey animals (Silberbauer, 1981).

A number of irrational beliefs about animals may be enumerated, but in general these seem to play a small role in the hunter's interaction with animals (Blurton Jones and Konner, 1976). It can be expected that rational scientific knowledge will be relatively more important, since the success of the hunt depends on its predictive value. However, irrational beliefs may well affect the outcome of a hunt. The sight of a hovering Bateleur eagle may motivate the hunter, thereby increasing his chances of success. Or the belief in the steenbok's magical means of avoiding arrows may cause the hunter to take extra care when stalking it, thereby increasing his chances of shooting it.

Cultural traditions vary greatly among the various Khoisan groups, so that a complex, interpenetrating patchwork of systems of belief is spread over large areas. Religion and folklore can only be discussed by referring to specific groups, specific places and historical times. There is not only a diversity of belief between groups, but also within single groups. This diversity is partly due to the impact that outstanding individuals may exercise on local traditions. These are then further complicated by outside influences (Biesele, 1978).

All story traditions of Khoisan hunter-gatherers are homogeneous in one important respect: all animals were formerly people and only later became animals. Stories deal with animals in their human aspect, though the characters already possess traits that will be typical of their animal aspect. The characters may turn into animals when they find themselves in situations where they need their animal powers. Such stories thus often account for the origins of different species (Biesele, 1976; 1978; Blurton Jones and Konner, 1976). Although this account of the origin of animal species may seem peculiar from a modern evolutionary point of view (almost a type of instant reverse Lamarkian adaptation), it is quite plausible from the tracker's point of view. Trackers identify themselves with an animal by thinking what they would do if they *became* that animal. It follows that an animal, with its human characteristics attributed to it by hunters in their anthropomorphic reconstruction of animal behavior, once *was* human and acquired animal characteristics when it needed them.

The religious beliefs of hunter-gatherers are central to their world-view in that such beliefs articulate their diverse areas of knowledge and belief in a coherent whole. The same variation exists in the details of their religious beliefs, as exists in the details of their general knowledge. Yet most groups of Khoisan hunter-gatherers believe in a greater and a lesser god. In general the greater god is regarded as a supreme good being and the creator. It is omnipotent, omnipresent, eternal and omniscient. It is known to be anthropomorphic, or at least the human shape is one of the shapes it assumes. Its human characteristics, however, are only part of its identity, the totality of which is beyond human comprehension. The lesser god is treacherous and vengeful. While good fortune is usually attributed to the will of the greater god, misfortune is attributed to the lesser god (Silberbauer, 1981; Biesele, 1978).

Hunter-gatherers are pragmatic and realistic in their outlook on the world. The religious beliefs of the !Xõ, for example, are not characterized by fear, intimidation or haunting. When !Xõ hunters fear something, that fear is well founded. They fear things which they know are dangerous, such as snakes, leopards and lions. All phenomena which they cannot readily understand are attributed to the will of the greater god. The !Xõ are aware of their own limitations and ignorance of things, thereby exhibiting a deep sense of religious humility (Heinz, 1978a).

Religious belief is so integral to the hunter's way of thinking that it cannot be separated from hunting itself. At the end of the day, if they have had no luck in tracking down an animal, !Xõ hunters may say that god did not "give" them an animal that day. If, on the other hand, they have had a successful hunt, they may say that god was good to them.

Hunter-gatherers tend to be monotheistic (Barnard, 2011). Belief in mythology and religion does not invalidate the validity of the scientific knowledge of hunter-gatherers. A clear separation between science and mythology is not always maintained by modern scientists.

Fundamental similarities occur in the nature of science and mythology. The line of demarcation between science and metaphysics cannot be drawn too sharply, and it may be argued that most scientific theories originate in myth (Popper, 1963). Science is much closer to myth than scientific philosophy may be prepared to admit and the two overlap in many ways (Feyerabend, 1975). The fact that some scientists derived ideas from non-scientific domains of thought does not invalidate the scientific merits of their work. Newton, for example, studied religion, magic and alchemy. Newton's concept of force, the major innovation of his scientific work, derived from concepts of occult powers in the natural magic tradition (Henry, 1988). In the conclusion to *Principia*, Newton wrote that "This most beautiful system of the sun, planets, and comets, could only proceed from the counsel and dominion of an intelligent and powerful Being" (Newton, 1687). Einstein (1954) maintained that "science without religion is lame, religion without science is blind." And in a letter to Max

Born, he explained that he could not accept the statistical laws of quantum mechanics as the fundamental laws of physical reality, because he believed that "God does not play dice with the world" (Clark, 1973). Paul Davies (1983) claims that science offers a surer path to God than religion.

There is a fine line between theoretical science and mythology. In the initial stages of development, scientific theories may be indistinguishable from myths. String theory cannot make a single novel prediction that can be tested empirically with current technology (Woit, 2006). One of the main arguments in favour of string theory, which unifies all known physical theories of fundamental interactions in a single coherent description of the universe, is that a theory with such mathematical beauty cannot be wrong. But physicists such as David Lindley have warned that in its search for a unified theory, physics was in danger of becoming mythology rather than science (Lindley, 1993).

Skepticism and Individualistic Theories and Hypotheses

Belief in myths varies considerably amongst trackers – some are more skeptical than others. Three trackers, !Nate, /Uase and Boroh//xao, of Lone Tree in the central Kalahari, told me that the Monotonous Lark (*Mirafra passerina*) only sings after it has rained, because 'it is happy that it rained.' One tracker, Boroh//xao, told me that when the bird sings, it dries out the soil, making the roots good to eat. Afterwards, !Nate and /Uase told me that Boroh//xao was wrong – it is not the *bird* that dries out the soil, it is the *sun* that dries out the soil. The bird is only *telling* them that the soil will dry out in the coming months and that it is the time of the year when the roots are good to eat.

Some trackers make a clear distinction between myths and religious beliefs, on the one hand, and knowledge based on empirical evidence, on the other. !Namka, a tracker from Bere in the central Kalahari, Botswana, told me the myth of how the sun is like an eland, which crosses the sky and is then killed by people who live in the west. The red glow in the sky when the sun goes down is the blood of the eland. After they have eaten it, they throw the shoulder blade across the sky back to the east, where it falls into a pool and grows into a new sun. Sometimes, it is said, you can hear the swishing noise of the shoulder blade flying through the air. After telling me the story in great detail, he told me that he thinks that the 'Old People' lied, because he has never seen any evidence that it is true. He has never seen the shoulder blade fly through the sky or heard the swishing noise.

Xamaha, one of my translators, has been to school and is fluent in English and can read and write. He no longer believes in the stories of the Old People... they are just stories. He has been taught about stars and planets at school, and has been taught that the traditional knowledge and mythology of his people are not true. He is nevertheless an excellent story teller, and even told some of the stories to me in English. He represents the new generation brought up on Western schooling, who never learnt traditional hunting and gathering skills.

!Nate's Cosmology

!Nate represents the transitional generation. He has not been to school, since he could not see any use for learning to read and write on papers. He wanted to learn in the bush about the *real* world. When I first met !Nate in 1985 he was a young man who decided that he wanted to become a hunter, because when all the cattle die during drought years, he would still be able to hunt wild animals. At a time when most young men aspired to a Western way of life and were no longer interested in the old ways, he was a rare exception to the rule.

!Nate does not believe in the story the Old People told about the people who eat the sun. He has never heard the noise the bone is said to make in the evening as it swishes overhead to the east. And why have they never seen any photographs of these people? Surely we would have seen pictures of these people in the newspapers if this story was true? However, he has not been taught that the Earth is round and that planets revolve around the sun. His conception of the Earth is still the traditional belief that the Earth is flat and goes down forever. Underneath the earth there is an endless sea of water (as is evident from the fact that boreholes provide an unlimited supply of water for cattle). !Nate invented his own theory to explain the movement of the sun.

The sun, according to !Nate, chases the shade. This can clearly be seen by the long shadows cast by trees in the early morning, which is then chased underneath the trees as the sun rises, and then chased to the other side as the sun goes down. The sun is like a round ball with a flat surface facing down towards the Earth. The flat surface shines like a torch and behind this surface, in the back of the sun, is its batteries. The sun is chased across the sky by the wind in the same way that the wind chases the clouds across the sky. When the sun goes down it goes into a hole in the ground which has a diameter of about four meters (he drew a circle on the ground to show me). When the sun goes into this hole, it chases the night from underneath the Earth out the other side, in the same way that it chases the shade. The sun has its own path underneath the Earth, and the sun itself is chased down this path by the flow of the water underneath the Earth. As the sun moves through the water, it causes vapor to come up through the ground. This is why the night gets cold and dew is formed. When the sun comes up through its hole in the east, it chases the night down the other side underneath the Earth. The early morning sun is cold because it is still wet. As the wind chases it across the sky it dries out so that by midday the sun is hot again.

When I asked !Nate who told him this story, he proudly told me that it is his own explanation that he invented himself. He was clearly pleased to see how impressed I was with the ingenuity and beauty of his logic. However, his explanation seemed to have one flaw. I asked him why the sun's batteries do not go flat. Stumped for a moment, he paused to think ... and then with a triumphant glint in his eyes he gave me the infallible answer: "Because it is God's batteries!"

Looking closely at !Nate's cosmology, we see that it all boils down to one axiomatic assumption, or "law of nature": that objects are moved by the movement of the medium they find themselves in. His hypothesis is in a sense the opposite to the assumption of 19th Century physicists that there existed a stationary medium, representing absolute space, called the "ether." When the medium of air moves, we know from direct experience that leaves are moved by the wind and that clouds are moved across the sky. Therefore the sun is also moved by the wind. Similarly, we know from experience that leaves are moved on the surface of moving water, flowing down a stream. So the sun is moved by the water underneath the earth. The metaphor for making something move is "chasing" – like a hunter chasing an antelope. This is a beautiful example of causality, simplicity, internal consistency and completeness (see *Thematic Presuppositions*, Chapter 8).

In the light of what we know today, !Nate's cosmology is clearly not a true model of our solar system. However, modern String theory has no claim to be a "scientific theory" any more than !Nate's theory - at least until String theory can produce novel predictions that can be tested. String theory may well produce testable predictions in the near future, or maybe in fifty or a hundred years from now. Or, as in the case of the heliocentric model of the solar system proposed by Aristarchus, it may take more than a thousand years. But until it does, it is epistemologically equivalent to a sophisticated myth and, like !Nate's cosmology, it may simply be wrong.

6

The Evolution of Tracking

Tracking an Aardvark

Half way up the mountain I found a small rock that was freshly displaced, the only sign that an animal had passed that point. I have been following an imaginary route up the mountain, with no signs of disturbance at all. I was tracking an aardvark over rocky terrain, where footprints are difficult and sometimes impossible to see. The terrain in the Klein Karoo is mountainous, with sandy flood plains in the valleys. In the flood plains it is relatively easy to follow tracks, but as soon as you go up the slope onto the side of a steep hill or mountain, it becomes very rocky, with barely any sand at all to leave tracks. The aardvark has thick, strong claws, which makes it easy to follow on sandy ground, but the claws may also leave feint scuff marks on rocky surfaces, especially if there is a thin layer of wind-blown dust collecting in rocky crevices.

Tracking the aardvark in the sandy floodplain made it possible to get a general direction as it headed up the side of the mountain, but as soon as it walked onto the rocky ground, its footprints disappeared. The aardvark has short legs and tends to avoid going over boulders, so I could visualize the most likely route it followed amongst the boulders. Following the easiest path in the general direction up the mountain slope, I could find pebbles that were freshly displaced and the occasional scuff mark on a flat rock. But at one point I completely lost the trail. Looking up at the steep mountain side, I visualized a path going up to the top, and by following the imaginary path, found the one displaced rock, which could have been a sign of the aardvark, but I was not sure. But it was the only sign, so working on the *assumption that is was the aardvark, headed up to the top of the mountain. As the ground started to flatten at the top, with sandy areas, I found some fresh tracks where the aardvark was digging for termites. The trail went down the other side of the mountain, and down into the next valley where footprints were once again easy to follow in the sandy ground. Once again it headed up the next slope, where I lost the trail, but were able to follow an imaginary path over the rocky, boulder-strewn mountain side. On the top, where there was sandy soil on the flat plateau, I again picked up the trail where it was digging for termites.*

On flat ground you invariably find more sandy soils, where it is easier to track animals. On steep mountain slopes sandy soils are usually eroded and washed away, leaving barren, rocky ground. But the contours of the mountain side, together with boulders that channel the movements of animals, make it easier to predict the path an animal would have followed. Nevertheless, when an animal changes direction in an unexpected way, and there are no scuff marks or displaced pebbles to indicate the path it followed, it can simply become impossible the follow the trail. It then requires a lot of persistence to search all the possible routes it may have followed until you find fresh tracks in a sandy area.

Simple, Systematic and Speculative Tracking

Tracking may well have originated in following animals like the aardvark in flat, barren, sandy conditions where it is easy to follow tracks. Once you have found their burrow, they do not take flight – you simply need to dig them out. This may have been the original context for tracking animals that are easy to kill once you have found them.

From easy sandy conditions through to hard, rocky terrain, tracking can become increasingly difficult, to the point where it becomes virtually impossible to track an animal. In order to reconstruct how tracking may have evolved, we need to distinguish between three levels of tracking: simple, systematic and speculative.

Simple tracking may be regarded as following footprints in ideal tracking conditions where the footprints are clear and easy to follow. These conditions are found, for example, in soft barren substrate or snow, where footprints are not obscured by vegetation and where there are not many other animal tracks to confuse the tracker.

Systematic tracking involves the systematic gathering of information from signs, until a detailed indication is built up of what the animal was doing and where it was going (see Chapter 5). It is a more refined form of simple tracking, and requires an ability to recognize and interpret signs in conditions where footprints are not obvious or easy to follow.

Speculative tracking involves the creation of a working hypothesis on the basis of the initial interpretation of signs, knowledge of animal behaviour and knowledge of the terrain. Having built a hypothetical reconstruction of the animal's activities in their mind, the trackers then look for signs where they expect to find them (see Chapter 5). Instead of "following" footprints the speculative tracker predicts where tracks will be found. In difficult terrain, where tracks are not easy to see, this makes tracking much faster.

Simple and systematic tracking both involve empirical knowledge based on inductive-deductive reasoning (see Chapter 8), but systematic tracking in difficult tracking conditions requires much greater skill to recognize signs and probably a much higher level of intelligence. Tracking conditions may vary considerably, so that the degree of difficulty may vary gradually from very easy to very difficult. One cannot make a clear distinction between simple and systematic tracking. The difference lies in the degree of skill, and the skill required for systematic tracking depends on how difficult tracking conditions are.

In contrast to simple and systematic tracking, speculative tracking involves creative science based on hypothetico-deductive reasoning (see Chapter 8). Speculative tracking involves a fundamentally new way of thinking.

The suggestion that speculative tracking, as practiced by recent hunter-gatherers in savanna-woodland conditions, requires above average modern creative scientific intellectual abilities (see Chapter 5), implies that it is unlikely that tracking could have originated in a savanna-woodland habitat. It is most likely that tracking evolved in conditions where tracking is easiest. Simple tracking may have developed into systematic tracking in increasingly difficult tracking conditions. Speculative tracking may have developed in very difficult tracking conditions where systematic tracking became inefficient. Modern trackers practice a combination of systematic and speculative tracking, and the two types of tracking play complementary roles.

The Origin of Tracking

Ideal conditions for simple tracking are found in arid environments with sandy substrate where the ground is sparsely covered with vegetation.

Homo species appear the first to be adapted to open, arid environments (Reed, 1997). As hominins migrated to or evolved in more open arid environments, vegetable foods would have been less abundant, and hominins may have had to increase the percentage of meat in their diets. Open areas, however, usually contain lower animal population densities and decreasing opportunities for scavenging. Hominins may have had to depend to a greater extent on hunting for subsistence. But conditions for tracking would also have been easier and the development of tracking would have greatly increased their hunting success.

In relatively open country with high animal densities, such as savanna grasslands, hominins may have been able to locate animals by scanning an area, and then running them down in plain sight. However, such ideal conditions are rare, and more typically animals run out of sight, or the target animal may simply mingle with the herd, making it difficult to run down a particular animal in plain sight. Using weapons to wound animals would have increased their chances of running them down, but effective missile weapons are relatively recent inventions. Where visibility was limited (due to hills, dunes or vegetation), and with ideal tracking conditions, hunters could simply follow the footprints of animals which had run out of sight. As the animal had already been seen and associated with the footprints, this represents the simplest form of tracking, involving only basic spoor interpretation.

In terrain where visibility was limited with low animal densities, however, hunters would have had very limited success in locating animals by scanning. It would therefore have been necessary to locate animals by means of simple tracking. In such circumstances, the hunters would have needed at least to recognize footprints. In addition, a number of skills would have improved their chances of success. Firstly, the ability to determine the direction of travel would have doubled their chances of success, since they would not have followed the spoor in the wrong direction. The ability to recognize fresh spoor would have given hunters a reasonable chance of overtaking the animal. An ability to determine the speed of travel, either by the way sand had been kicked up, or by the relative position of footprints, would have enabled hunters to concentrate on the spoor of slow-moving animals. Finally, the ability to recognize the spoor of specific animals may have allowed hunters to select the spoor of animals that are easiest to run down or that give the greatest amount of meat.

One biome in which tracking may have originated is in a relatively barren semi-desert or desert environment. Here, ideal tracking conditions would be determined by the substrate, vegetation cover, animal population densities and weather conditions. It is much easier to track in soft, sandy substrate than in hard, stony substrate. Spoor may not be well defined in soft sand, however, so it may be difficult to interpret. Lacking definition, it may also be confused with similar but older spoor, since the colour differences between fresh and old spoor in dry, loose sand may be very subtle. However, when old spoor are wind-blown, very fresh spoor may be distinguished by having sharp edges. The sparseness of the vegetation cover also determines how easy it is to follow spoor. In semi-desert or desert environments animal population densities may be very low, leaving fewer proximate signs to confuse the tracker.

Two kinds of weather conditions play an important role in simple tracking. After wind has obliterated all old spoor, it is much easier to follow the spoor of a particular animal, although that spoor may also be obliterated by the wind. For simple tracking, ideal weather conditions would be a strong wind during the night so that all old spoor is obliterated, leaving only fresh spoor made after the wind has stopped blowing, with no wind blowing while the hunter follows the spoor. In practice the wind may vary throughout the day, sometimes making it easier for the hunter and other times making it more difficult. A very light wind may also obliterate spoor in exposed areas, such as the tops or upwind sides of dunes, while footprints in sheltered areas may be preserved. A trail may therefore be obliterated partially, leaving gaps where the spoor may be lost.

When rain has obliterated old spoor, fresh spoor are easier to follow. Footprints in wet sand are also much clearer than in loose dry sand where footprints may lack definition. It is also much easier to distinguish one set of spoor from another in wet sand. Footprints remain clear much longer in wet sand, even after the sand has dried into a crust. In arid environments it does not rain very often, however, so such opportunities would be limited. After good rains the ground may be covered more densely with grass. Conditions for simple tracking would therefore be more difficult in the rainy season than in the dry season.

A good example of ideal tracking conditions may be found in the semi-arid savanna such as in the southern Kalahari dunelands (page 115). These dunelands are characterized by long, roughly parallel dunes, sparsely covered with grass, shrubs and scattered trees. There is no natural surface water, and river beds may contain only occasional pools for a few months, weeks or days. In most years the rivers are entirely dry. On average about 10 rainstorms may account for about 150 mm of rainfall each year from February to May (Bannister and Gordon, 1983; Steyn, 1984b). Although there is no surface water for most of the year, animals obtain their moisture requirements from plants. The tsamma melon in particular is an important source of water for animals (Steyn, 1984b).

The most numerous large animal in the southern Kalahari is the gemsbok. The gemsbok prefers to frequent the dunes in the dry season, and goes down to the watercourses when rain falls. Its large size, relative abundance and preference for dunelands may have made the gemsbok one of the most important animals in the development of tracking in semi-arid environments. The sparse vegetation cover and soft sand would have provided ideal tracking conditions. The dunes would have offered limited visibility for scanning, since a hunter standing on top of a dune would not be able to see animals in the valleys beyond the nearest dunes, so making tracking a necessity.

In general, the most likely environment for the origins of tracking would have been an optimum combination of ideal tracking conditions, abundant wildlife, limited visibility which would have made tracking a necessity, and adequate water resources.

How Tracking Evolved

From ideal tracking conditions, one can discover a continuity of increasingly difficult tracking conditions. Tracking becomes more difficult as the substrate becomes harder, as the vegetation becomes denser and as the density of animal populations increases. Since tracking conditions may continuously become more and more difficult, the transition from simple tracking in ideal tracking conditions to systematic tracking in difficult conditions may have been very gradual. Such a gradual transition may, however, have occurred over a very long time or a relatively short time, depending on the selective pressures involved.

A continuum of increasingly difficult tracking conditions can be seen, for example, when the differences among the southern, central and northern Kalahari are considered (Fig. 4 to 9, pages 115 to 117). Throughout the Kalahari the substrate is mainly sand, so the main differences are determined by the steadily increasing rainfall from 150 mm per year in the southern Kalahari through to more than 600 mm per year in the northern Kalahari. While the southern Kalahari dunelands are relatively barren, the central Kalahari is characterized by open grasslands alternating with patches of bushes and trees or solitary trees, and the northern Kalahari by savanna-woodland.

While it is easy to follow footprints in barren sand, it becomes increasingly difficult as the grass becomes denser. Grass roots consolidate the soil, so that tracks remain visible for longer. In addition, the grass tufts protect tracks from being wind-blown, while in barren loose sand tracks are soon obliterated by the wind. On barren dunes the wind may leave a clean slate with fresh tracks that are easy to follow. Denser grass results in more proximate signs that may confuse the tracker.

In grassland it becomes necessary to recognize signs of animals in the way the grass is bent over in the direction of travel. As the vegetation becomes denser, systematic tracking becomes less and less effective.

In savanna-woodland, visibility is also limited by the vegetation, so hunters become increasingly dependent on their tracking abilities to locate animals. In such conditions systematic tracking may not have been adequate, and speculative tracking may have become a necessity. In woodland, speculative tracking is also more appropriate, since there are a limited number of routes that an animal can take through dense bushes, allowing the tracker to anticipate the most likely route taken. Animals are also more inclined to make use of paths among bushes.

Beyond the margins of the Kalahari, the wind-blown sands were, during wetter climates, carried away by fast-running waters. In the Kalahari, where sands collected in natural draining basins, no rivers carried away the sands. The sands remained, leaving the wind-blown Kalahari sands as the largest continuous stretch of sand in the world (Fig. 10, After Main, 1987). If tracking evolved in southern Africa, then the semi-arid savanna of the Kalahari would have been the most likely place.

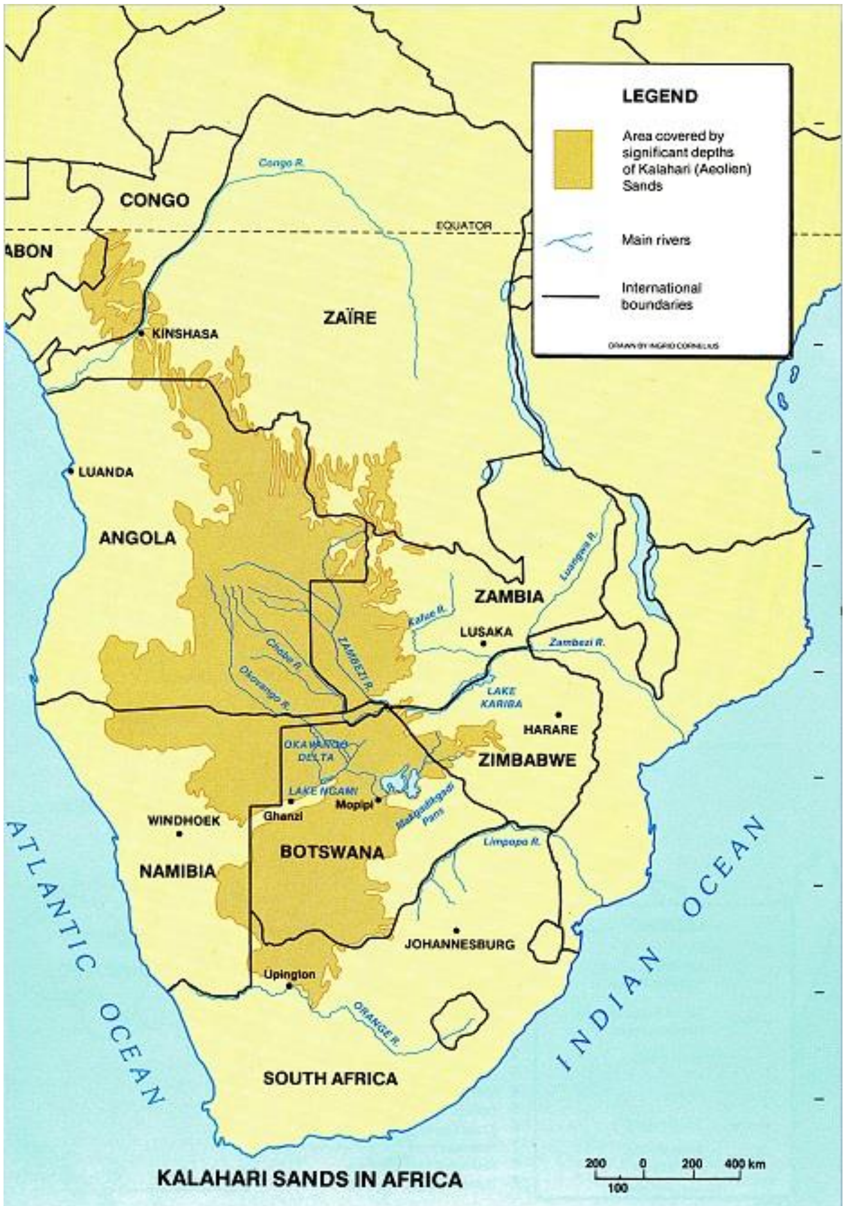


Fig. 10: Area covered by Kalahari Sands in Africa (after Main, 1987)

Apart from denser vegetation, harder substrate would also have made the transition from systematic to speculative tracking a necessity. Only with the development of speculative tracking may trackers have had a reasonable success rate in difficult tracking conditions, and hunter-gatherers have been able to adapt to a wide range of habitats.

Ideal tracking conditions and subsequent changes to difficult tracking conditions may have been caused by climatic changes. During the last glacial maximum, most low-latitude regions were relatively dry. The rainfall decreased, so that what had been savanna country dried up into near-desert. The semi-arid fringe areas around many deserts expanded. The rain forests of the tropics were reduced to isolated refugia, and some parts where there were forests, became active sand deserts. (Roberts, 1984).

During glacial maxima ideal tracking conditions may have existed in the more extensive arid low-latitude regions. During prolonged periods of drought expanding deserts resulted in active dune fields in the northern Kalahari (Cohen et al., 2007). The existence of fossil sand dunes beneath parts of the central African rain forest indicate that there were active sand deserts during the Pleistocene (Tricart, 1974). The arid conditions of the southern Kalahari may therefore have stretched over a much larger area than today. A large part of southern Africa and possibly parts of central Africa could have been ideal for persistence hunting.

During the warmer interglacials, the arid low-latitude regions may have been reduced, forcing hunter-gatherers to adapt to higher rainfall conditions. A change from semi-desert conditions to savanna grassland and woodland conditions may have been instrumental in the evolution of simple tracking into systematic tracking and then into speculative tracking.

The present central and northern Kalahari consists of a mosaic of savanna-grasslands and savanna-woodlands. The sparsely vegetated dune fields of the southern Kalahari are the easiest terrain for persistence hunting. Moving north across the central Kalahari towards the northern Kalahari, tracking conditions become more and more difficult, with increasingly thicker vegetation and areas of woodland. Beyond the sandy areas, tracking conditions also become more difficult due to harder substrate. As arid areas expanded and contracted with climate change, a combination of environmental change and population pressure would have selected for increasing levels of tracking skills.

Climate change does not follow a smooth, gradual path, but is characterized by erratic fluctuations. Early hypotheses emphasizing only the unidirectional development of open vegetation do not capture the now-evident complexity of African climate variability. An emerging view is that African fauna, including our forebears, may have been shaped by changes in climate variability itself (deMenocal, 2011).

Generally a change from warm, wet environment towards a cool, dry climate takes place over longer periods, interspersed with short wetter periods. Changes from cool, dry conditions to warm, wet conditions may be more abrupt. Changes towards more arid conditions would have provided selection for increasingly sophisticated systematic tracking due to more sandy areas. Abrupt changes towards wetter conditions would have provided selection for speculative tracking due to thicker vegetation. On the other hand, extremely arid conditions may also have made large parts of the Kalahari inhospitable, forcing hunter-gatherers into areas of harder substrate, which would have provided selective pressure for speculative tracking.

Habitats in Africa such as the Kalahari may have played a role in selecting for increasing levels of tracking skills during periods of drought, alternating with wetter periods.

The Evolution of the Human Brain

The human brain is approximately five times larger than expected for our body size (Lieberman, 2011). At the same time as brain size began to increase in the human lineage, our ancestors, beginning with *Homo erectus*, shifted to a hunting and gathering lifestyle, with morphological evidence showing adaptations for increased long-distance trekking and the adoption of endurance running (Bramble and Lieberman, 2004).

The evolution of persistence hunting would have involved the evolution of tracking skills. The evolution of tracking would have involved the evolution of the cognitive abilities to engage in scientific reasoning. Increasing success rates in persistence hunting would further have provided higher protein intake, which would also have contributed to the evolution of a larger brain.

Social and ecological selection pressures played an essential role in human neurobiological evolution (Schoenemann, 2006; Dunbar, 2003; Barton, 1996; Dunbar and Shultz, 2007). However, over a period of two million years, the evolution of persistence hunting and the art of tracking may have made a significant contribution to the evolution of a larger brain.

Visual Perception and Imagination

The transition from systematic to speculative tracking would have required the evolution of a creative imagination. The creative imagination may have originated in the interpretation of visual tracks and signs. At any one time the human brain produces two visual images: an image of what we see through our visual perception of the real world and an image produced by our imagination.

Sometimes these two images may have no connection. You may be sitting in a garden and perceive images of plants and birds, while in your imagination you may visualize an experience you had in another place.

At other times the image perceived may evoke an imaginary image that is associated with it. You may see a person you recognize and in your imagination visualize another person you associate with this person. The image you perceive is connected to an image retrieved from your memory. However, these associations may be arbitrary. The sight of a person you know may evoke any number of associated images – you may associate the person with images of friends, family, the person's car, dog or home. When you see an object, animal or a person, you may at the same time produce an imaginary image that has an arbitrary association with the object or person you see.

However, when you look at a natural sign (such as an animal track), the act of recognizing the sign evokes an imaginary image of the animal that made the track. There is a non-arbitrary association between the perceived visual image of a track and the imaginary image of the animal associated with the track.

When looking at a partial sign, the images evoked in your imagination may involve three distinct steps. The track of a hyena may be mostly obliterated, leaving only one toe print visible. In addition, the toe itself may be partially obscured by a twig lying across it.

Firstly, your mind does not perceive two separate halves of the toe either side of the twig. Through amodal completion the incomplete outline (broken by the twig) of the toe may be perceived to be a complete outline. Your mind therefore perceives it as one toe, not two halves. This may be a preattentive process of visual perception, i.e. it does not require attention (Reijnen et al. 2009). You perceive the whole toe in an automatic and effortless manner, via amodal completion, without seeing the hidden part underneath the twig (Ramachandran and Rogers-Ramachandran, 2010).

Secondly, the visual image you perceive of the distinctive tear-drop shaped toe print and thick claw mark may evoke an imaginary image of an "ideal image" of the complete footprint, where you visualize four toes and the back pad in your imagination. This "ideal track image" is based on previous experience of studying both tracks and the feet of animals. This is not automatic or effortless, but requires considerable expertise. You need to know that only the hyena has toes that have this particular tear-drop shape. In addition, you need to know that no other animal of similar size (lion, leopard, cheetah or wild dog) have toes that have this particular shape. In your imagination you need to retrieve visual images from your memory and compare theses images and ask yourself: which of these animals have a toe that is shaped like the toe I see? This is complicated by the fact that tracks may vary considerably and may not correspond exactly to the "ideal image" you have retrieved from your memory. The expert tracker may be able to recognize it at a glance, but the inexperienced tracker may take ten to twenty minutes to identify it, and still get it wrong. Also, while you are visualizing four toes and a back pad in your imagination, you still only perceive one toe.

Step two combines details of tracks based on previous observations of both tracks and feet. You can only study the details of the feet of a dead animal, as hunters often do after killing an animal. The imaginary image of the complete footprint may correspond to an imaginary image of the shape of the underside of the foot of the animal that made the track. In a modern context, I have studied the feet of museum specimens and road kills (in addition to studying tracks found in the field) to produce the illustrations for my *Field Guide to Animal Tracks of Southern Africa* (Liebenberg, 1990b). This makes it easier to visualize the finer details of tracks, especially details that do not often show in tracks (you rarely find a perfect track). However, when you have never had the opportunity to study the foot of a dead animal, you learn tracks by seeing an animal and then going to the spot where you saw it to study its tracks. But since you hardly ever find perfect footprints and because footprints vary considerably, you need to study many footprints in order to accumulate all the information contained in the "ideal image" of a track. In a modern context, step two also involves visualizing the track illustrations in a Field Guide. I find that I usually visualize the track illustrations in my Field Guide when I analyze footprints.

Thirdly, the ideal image of the track may then evoke an imaginary image of the animal that made the track. The perceived visual image of a track is associated with an imaginary visual image of an animal that cannot be seen. In the past you associated a particular sign with a specific animal, so through inductive generalization you assume that the sign you see was made by that specific animal which you visualize in your imagination. In speculative tracking you use your imagination to visualize the behavior and movement of the animal to deduce where it was going, in order to predict where additional signs of that animal may be found.

Steps two and three involve non-arbitrary associations. The non-arbitrary association between the perception of natural signs and the imaginary visual images evoked by signs may suggest that human visual imagination may have had its origin in the interpretation of tracks and signs.

Artificial signs, such as words on a page, may also evoke imaginary images with non-arbitrary associations. Seeing the word "lion" usually evokes an imaginary image of a lion. But reading and writing is a cultural invention created after modern humans evolved. It has in fact been argued by Edward Chamberlin (2002) that tracking, as described in my first book *The Art of Tracking: The Origin of Science* (Liebenberg, 1990), not only constitutes a form of reading that can be compared with the reading of other written texts, but it involves all the cognitive innovations identified with the development of modern European culture.

It is interesting to note that monkeys fail to show an understanding of visual signs. In field experiments, primatologists Dorothy Cheney and Richard Seyfarth hung a stuffed gazelle carcass from a tree and then observed how wild vervet monkeys behaved. The monkeys seemed oblivious to this sign of danger of a potential leopard in the area.

Similarly, the monkeys ignored python tracks (Cheney and Seyfarth, 1990).

Systematic tracking based on inductive-deductive reasoning may not require imaginary visual images. The systematic tracker may learn through trail-and-error to associate certain visual signs with specific animals, without understanding how the animal produced those signs (for example, whether the animal was walking or running). If tracks are easy enough to follow (such as in barren sand dunes), the tracker may find the animal by following perceived visual images of tracks without visualizing the animal that cannot be seen (in the same way that dogs probably do not visualize a scent trail). It is therefore conceivable that early hominins may have practiced systematic tracking without being able to create imaginary visual images of the animal that cannot be seen.

For speculative tracking, however, the creation of imaginary visual images of the animal is essential. The non-arbitrary connection between the visual perception of signs and imaginary visual images of animals may well suggest that the evolution of visual imagination was a prerequisite for speculative tracking. The interplay between perceived visual images of tracks and imagined visual images of the animal allow the tracker to predict the movements of an animal by means of hypothetico-deductive reasoning.

Speculative tracking not only allows the tracker to predict the movements of animals spatially, but also to simulate and visualize the future. Trackers constantly run simulations of reality in their heads. This is what gave humans the ability to predict evolving situations and formulate strategies. The ability to predict the future involves creating multiple models that approximate future events. This may well be one of the most fundamental attributes that distinguish humans from other animals.

Landmarks in the Evolution of Tracking

In the previous sections we have looked at how tracking may have evolved. In this section we will look at key landmarks that may give an indication of when and where the different levels of tracking may have evolved.

It is possible that tracking was first developed to find animals such as aardvark and porcupine sleeping in burrows. Hunters have all day to track the animal, and when an occupied burrow is found the animal does not run away. However, this may only have been possible when hominins adapted to marginal arid environments.

Major steps in the evolution of African hominins, and in particular the origin of the genus *Homo* and the evolution of *Homo erectus*, are coincident with shifts to more arid, open conditions near 2.7–2.5 Ma, 1.9–1.7 Ma, and 1.1–0.9 Ma (deMenocal, 1995; Trauth et al., 2005). First appearance and extinction events, as well as key behavioral milestones, cluster between 2.9 and 2.6 Ma and again between 1.9 and 1.6 Ma (deMenocal, 2011). The expansion of grasslands across the Pliocene–Pleistocene transition has been linked to global climate change and major developments in the hominin clade, such as the more obligate bipedalism of the genus *Homo*, increase in encephalization, and reduction in tooth and gut proportions (Cerling et al., 2011).

Evidence suggests that hominids were actively hunting, at least by the time that *Homo erectus* appears circa 1.9 Ma (Potts, 1988; Bunn, 2001; Dominguez-Rodrigo, 2002). It is therefore possible that systematic tracking may have evolved with the evolution of *Homo erectus* as much as two million years ago.

Initially *Homo erectus* may have practiced persistence hunting in habitats like the Kalahari, but did not have the skill to do persistence hunting in harder terrain, where it would have done mainly scavenging. Only when a

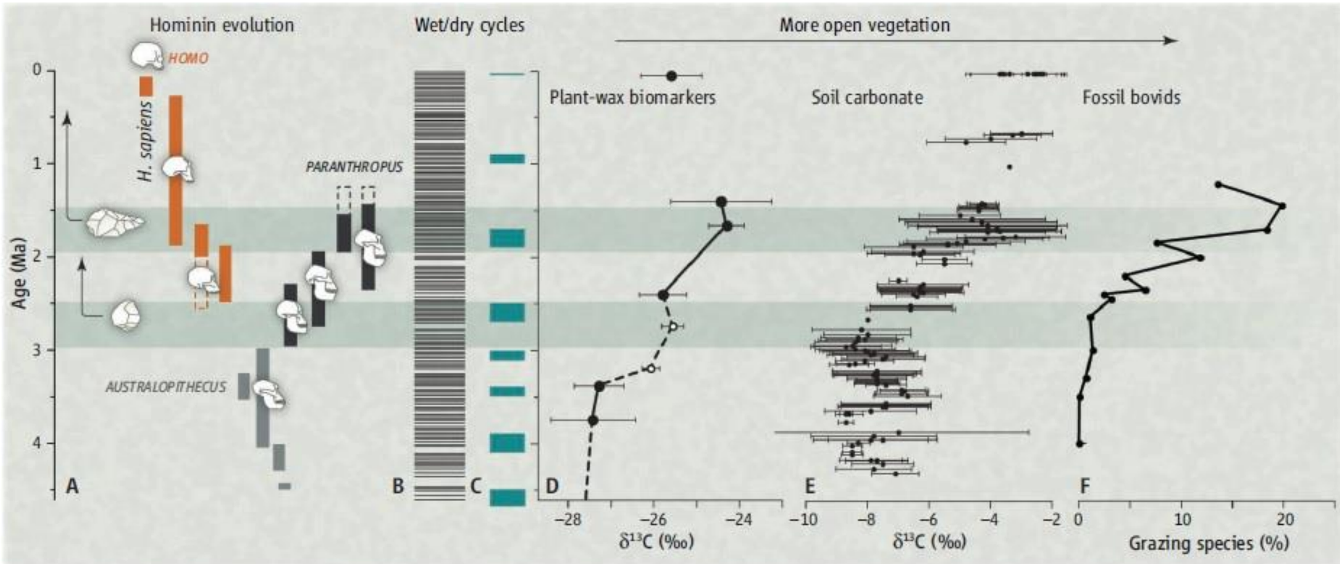


Fig. 11: Major steps in the evolution of African hominins are coincident with shifts to more arid, open conditions near 2.8 Ma, 1.7 Ma, and 1.0 Ma, suggesting that some speciation events may have been climatically mediated. First appearance and extinction events, as well as key behavioral milestones, cluster between 2.9 and 2.6 Ma and again between 1.9 and 1.6 Ma (after deMenocal, 2011).

certain level of tracking skill developed would persistence hunting have been possible in more difficult areas (in extremely hard, rocky terrain it may never have been possible). Tracking probably did not evolve sequentially at the same time throughout Africa. Depending on the terrain, each level of tracking may have originating in the Kalahari (since it is the largest continuous stretch of sand in the world) and then radiated out to a patchwork of areas elsewhere in Africa where the terrain made that particular level of tracking and persistence hunting possible. Only with the invention of the bow-and-arrow would it have been possible for humans to hunt and track in all types of terrain.

The instability of the climate during both glacial and interglacial periods (Dansgaard et al, 1993) may have resulted in a number of disruptive environmental changes from about 200 000 to 70 000 years ago. Modern humans emerged in Africa by about 200 000 years ago (McDougall, Brown and Fleagle, 2005). It is possible that humans at that time may have had the potential to practice speculative tracking. The long glacial stage known as the Marine Isotope Stage 6 lasted from 195 000 to 123 000 years ago, when it was cool and arid with expanded deserts (Marean, 2010; Foley, 1984). With the change towards wetter conditions about 123 000 years ago, increase in grasslands and then woodlands would have selected for increasingly sophisticated speculative tracking.

Speculative tracking would have been a prerequisite for hunting with bow and arrow, for which the earliest evidence was found at two sites in South Africa and dates to 64 000 years ago (Lombard and Phillipson, 2010) and 71 000 years ago (Brown, et al, 2012) respectively. Evidence of symbolic activities, including both red ochre and seashells that were clearly collected for their aesthetic appeal, date back to 110 000 years ago in South Africa (Marean, 2010). Abstract representations engraved on pieces of red ochre recovered from the Blombos Cave in South Africa suggests that, at least in southern Africa, *Homo sapiens* was behaviorally modern about 77,000 years ago (Hensilwood, et al. 2002). Evidence of advanced cognitive abilities may indicate the potential intellectual capacity to practice speculative tracking and therefore scientific reasoning. Evidence of art may also be indirect evidence of science (see Chapter 9). It is therefore likely that speculative tracking, and therefore creative science, evolved at least by about 70 000 years ago and possibly more than 100 000 years ago.

It has been suggested that genetic evidence supports the hypothesis that modern humans originated in southern Africa (Tishkoff, et al, 2009; Henn, et al, 2011). If speculative tracking evolved in southern Africa, then it is possible that the Kalahari may have played an important role in the evolution of tracking and the origin of creative science.

The Logistic Growth of Knowledge

In Chapter 7 we propose that the evolution of scientific knowledge followed a logistic growth curve since its origins more than a hundred

Fig. 12: The logistic growth of knowledge, from empirical knowledge through to creative science:

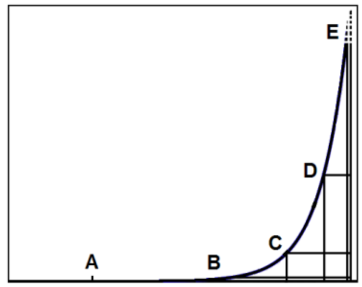


Fig. 12A: On scale of more than 2 million years:

A) More than 2 million years ago: Evolution of endurance running for increasingly efficient scavenging, but not sufficient for persistence hunting. Simple tracking used for animals like Aardvark that can be trapped in burrows. Gradual evolution of basic empirical knowledge.
B) About 2 million years ago: Endurance running sufficient to run down animals using systematic tracking, while still relying mostly on scavenging. Evolution of empirical knowledge based on inductive-deductive reasoning.
C) Persistence hunting using increasingly sophisticated systematic tracking, while still relying on scavenging. Evolution of increasingly sophisticated empirical knowledge.
D) About 200 000: Persistence hunting using increasingly refined speculative tracking, while still using systematic tracking in easier terrain and scavenging. Evolution of creative science based on hypothetico-deductive reasoning.
E) About 100 000 to 70 000 years ago: Speculative tracking with bow-and-arrow, language, art and creative science.

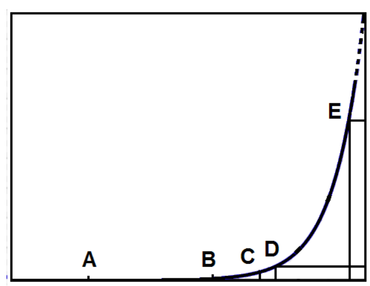


Fig. 12B: On a scale of more than 200 000 years:

A) About 200 000 years ago or more: Evolution of creative science based on hypothetico-deductive reasoning. Stone tools indicate increasing levels of innovation.
B) About 110 000 years ago: Red ochre and sea shells indicate a sense of aesthetics.
C) 77 000 years ago: Engraved red ochre at Blombos Cave, South Africa, evidence of use of symbols.
D) 64 000 years ago: Earliest evidence of bow-and-arrow in South Africa, allowing speculative tracking in increasingly difficult tracking terrain.
E) Agriculture and the evolution of Egyptian and Babylonian science.

thousand years ago. In the same way, the evolution of tracking probably followed a logistic growth curve over a period of two million years.

Just as the development of technology follow logistic growth, the evolution of simple tracking skills would initially have been relatively slow, gradually developing increasingly sophisticated systematic tracking skills, and eventually evolving into speculative tracking. Compared to Moore's Law in computer technology, which seems to grow incredibly rapidly over a short period of time, the logistic curve describing the evolution of tracking would have been very flat and very slow, growing imperceptibly over a period of two million years. In this view, most of this period would have seen very gradual evolution of simple and systematic tracking skills, and only "recently" (perhaps over the last 200 000 years) developing into highly creative speculative tracking.

The suggestion that modern tracking, as practiced by recent hunter-gatherers, requires scientific intellectual abilities (see Chapters 5 and 8) also implies that it is unlikely that such abilities developed before the evolution of the modern intellect. As the modern brain evolved, hunters would have had the potential to develop modern tracking. Modern tracking may have been developed only some time after the modern brain evolved. However, if hunters were already practicing systematic tracking, it would be surprising if they did not develop speculative tracking as soon as they had the ability to do so. If speculative tracking developed at the same time that the modern brain evolved then selective pressures for speculative tracking and scientific reasoning may have been at least partially responsible for the evolution of the modern brain.

It has been suggested that systematic tracking have been practiced by some *Homo erectus* populations, possibly as much as two million years ago. By the time *Homo sapiens* appeared, it is likely that hunters were highly skilled systematic trackers and had the potential to practice speculative tracking. The evolution of speculative tracking and creative science may have occurred more than a hundred thousand years ago in southern Africa in the Kalahari Desert.

7

The Evolution of Science

In this chapter I will develop a model of the growth of science based on an evolutionary definition of science that will explain how science evolved through natural selection.

Scientific Revolutions

Philosophers and historians have described science as something that was invented at a particular point in history and then developed over time as essentially a historical process. It has been assumed that science was first developed by the Ionian school of Thales (Popper, 1963) or that "The Scientific Revolution" occurred in Western Europe.

Writers like Thomas Kuhn (1957, 1962) have entrenched the perception that the history of science consists of a series of scientific revolutions. Furthermore, he maintained that a scientific revolution involved a paradigm shift that resulted in a new perception of the world that was incommensurable with the previous world view. From a Western European point of view, there is a common perception that *the* "Scientific Revolution" occurred during the Renaissance and that the origin of "science" is associated with names like Copernicus, Kepler, Galileo and Newton (see, for example, the popular book *Science: A History*, 2002, by John Gribbin).

However, Steven Shapin (1996) argues that there was no such a thing as "the Scientific Revolution." There was no singular and discrete event, localized in time and space, which can be pointed to as "the" scientific revolution. Shapin even rejects the notion that there was any single coherent cultural entity called "science" in the seventeenth century to undergo revolutionary change. There was continuity between seventeenth-century natural philosophy with its medieval past, while there were "delayed" eighteenth- and nineteenth-century revolutions in chemistry and biology.

Looking at more recent developments in the history of science, Gerald Holton (1998) argues that major scientific advance can be understood in terms of an evolutionary scientific process. Einstein saw himself not at all as a revolutionary, but saw his role as a member of an evolutionary chain. He regarded his relativity theory as "a modification" of the theory of space and time. He maintained that: "We have here no revolutionary act but the natural development of a line that can be traced through centuries" (Holton, 1986).

In *A People's History of Science* (2005) Clifford Conner demonstrates continuities between prehistoric knowledge and modern science. He argues that the hunter-gatherers' mastery of their natural environment had lasting consequences; their observation and experimentation laid the foundations of astronomy, botany, zoology, mineralogy, geography, oceanography, and many other sciences.

The Logistic Growth of Scientific Knowledge

What may appear to be a "recent" exponential explosion of the "Scientific Revolution" may simply be a continuous logistic growth curve that goes back more than 100 000 years.

If one looks at the development of stone tools one sees an "explosive" growth in the Late Stone Age and the Upper Palaeolithic about 50 000 years ago. We see early forms of notation in the form of inscriptions and engravings in bone (Marshack, 1972). Similarities between Egyptian and Babylonian mathematics imply considerable intellectual interaction, which was the inheritance of the Greeks (Rudman, 2007). Rudman (2010) argues that the Babylonians used geometric algebra to derive the Pythagorean theorem, or as he calls it the "Babylonian Theorem," about a millennium before its purported discovery by Pythagoras.

If one were living in Greece in the year 300 BC, one would have witnessed an "explosion" of science and philosophy during the preceding 300 years. The decimal system evolved in India about two thousand years ago and was introduced into Europe about one thousand years later in Latin translations of Arabic translations of Hindu texts (Rudman, 2007). If one lived in Istanbul in the 16th century, one would have witnessed an "explosion" of Islamic science during the preceding 800 years (during the "Dark Ages" of Western Europe) (Masood, 2009).

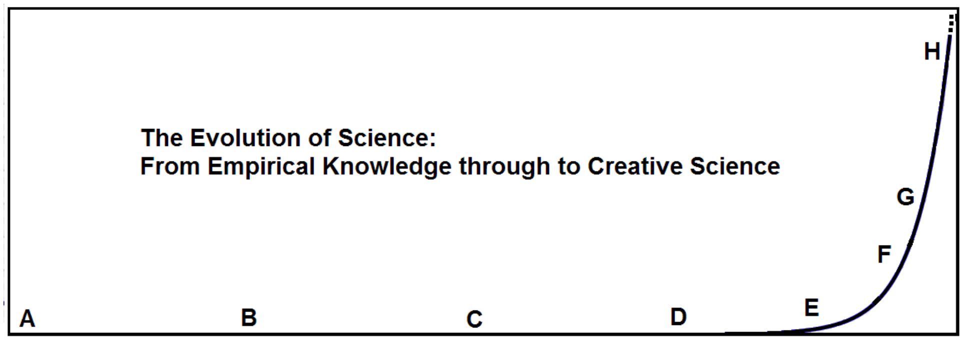
Today it appears as though there was an "explosion" of Western science in the last 400 years. A hundred years from now, people may look back at an "explosion" of science in the 21st century that will make the 17th century "Scientific Revolution" look primitive by comparison.

The only reason we now think the 17th century Western European "Scientific Revolution" was so significant is because the last 400 years is simply the most recent part of a continuous logistic curve that goes back more than 100 000 years.

From the beginning of the Universe the evolution of complexity has followed a logistic growth (Modis, 2002). In a sense it is looking back at Moore's Law in reverse. Granted, the previous 100 000 years were relatively flat compared to the last 100 years, but that is the nature of logistic growth driven by the positive feedback of creative innovation and population growth. Given this perspective, I would argue that the choice of modern Western European culture is an arbitrary point in history – it just happens to be the period immediately before the present.

The apparent "exponential" growth (the initial phase of logistic growth) we have seen over the last 100 000 years is probably the initial upward curve of a logistic S-curve that may eventually slow down and flatten out (see Modis, 2002; Modis, 2006).

Fig. 13: Applying logistic growth to the evolution of science:



A) About 2 million years ago: Basic Empirical Knowledge of Simple Tracking and Plant Foods
B) Systematic Tracking and Plant Foods: Empirical Knowledge based on Inductive-Deductive Reasoning
C) About 200 000 years ago: Speculative Tracking – Evolution of Creative Science based on Hypothetico-Deductive Reasoning
D) Egyptian and Babylonian Science
E) Greek Science
F) Islamic and Chinese Science
G) Western European Science
H) 21st Century Global Science, involving citizen science and intelligent computers to explore increasing levels of complexity.

The initial "flat" part of this curve (A to D) represents logistic growth. If you decreased the horizontal axis and increased the vertical axis, the curve would look like the diagrams in Fig. 12, page 130. At any point in history, the logistic curve may have had the same appearance, creating the impression of a "recent" explosion in scientific knowledge. However, the growth of knowledge may not have followed a smooth curve. Rather, it may have advanced in cycles of growth and setbacks. But averaged over time, the general trend would have been a logistic curve.

An Evolutionary Definition of Science

I would argue that the success of science cannot be explained if it is assumed that science was invented in recent historical times. A purely historical explanation of science cannot explain the success of science or how the human mind evolved the ability to do science. Only by looking at science as a product of natural selection in the evolution of humans can we explain why science is so successful.

What are the definitive requirements of “science”? The seventeenth-century “Scientific Revolution” has been associated with a variety of external props, such as the printing press, scientific instruments and a culture of free debate and exchange of information and ideas (Carruthers, 2002).

After the development of a sophisticated language, the inventions that have had perhaps the greatest impact on science were writing, mathematics, the printing press, computers and the Internet. These inventions have dramatically increased our capacity to share knowledge and have accelerated the rate of new discoveries. But what makes the printing press a definitive requirement of science? Why not hand-written copies of manuscripts, or why not early forms of writing in the form of inscriptions and engravings in bone? (see Marshack, 1972) Why not computers? Scientific instruments may have opened up new fields of science, but no single instrument is a prerequisite of science in general. The fact that some fields of science do not use the telescope does not make them “less scientific” than astronomy. Or that some do not use the microscope does not make them “less scientific” than microbiology. The fact that scientific instruments have advanced many new fields of science does not mean that fields that do not use scientific instruments are not science.

Writing, the printing press, scientific instruments, computers, the Internet and a culture of free debate have dramatically increased the capacity and refinement of science. Each one of these innovations had a major impact on the evolution of science. How does one decide which of these external props was the most fundamental and therefore *the* definitive requirement of "science"?

The various continuities between tracking and science seem to be sufficient to warrant the claim that anyone having a capacity for sophisticated tracking will also have the basic cognitive wherewithal to engage in science (Carruthers, 2006).

From the art of tracking through to modern science there is continuity in the most fundamental core characteristics of science (such as the cognitive abilities required to engage in science), while a number of innovations (such as writing, the printing press, scientific instruments, computers, scientific methodology) were added over time. The art of tracking may have characteristics {a,b,c}, while modern science may have characteristics {a,b,c,d,e,f,g,h,i,j,k}. Through the ages it may be possible to define "science" as having the requirements {a,b,c,d}, or {a,b,c,d,e}, or {a,b,c,d,e,f}, depending on where in history you choose to define the "origin of science." But such a definition would be arbitrary, and therefore would not explain anything about the nature of science. Any arguments used to justify such a definition would be circular - the "origin of science" occurred when the minimum requirements {a,b,c,d,e} were developed, because we define "science" as having the requirements {a,b,c,d,e}.

Perhaps the most fundamental transition occurred when modern humans evolved the basic cognitive capacity to engage in scientific reasoning. Before this transition in human evolution the capacity to engage in modern science did not exist. Developing the cognitive capacity to engage in science required *biological evolution,* while the subsequent development of science involved *cultural evolution.* This is not just an arbitrary point in history, since it involved a discontinuity that was fundamentally different from the cultural evolution that followed. This discontinuity may have occurred when the human mind, previously only able to engage in inductive-deductive reasoning, evolved the cognitive ability to engage in creative hypothetico-deductive reasoning (see Chapter 8). This may have happened when systematic trackers evolved the ability to practice speculative tracking (see Chapters 5 and 6). While this transition represents a fundamental conceptual discontinuity, it may, however, have evolved over a substantial period of time.

I am therefore proposing an evolutionary definition of science. Scientific reasoning is an adaptation of an organism (*Homo sapiens*) that evolved through natural selection, thereby increasing its chances of survival. And as far as we know, humans are the only species that evolved the ability to develop science. Creative science is essentially a product of the human mind that allows humans to interact with reality in a way that increases our chances of survival.

The very nature of science is that it evolves over time. Scientific hypotheses and new theories require creativity, and this same scientific creativity also results in innovations in the nature of science itself. The similarities between tracking and modern science may explain how, through natural selection, we evolved the ability to do science. Conversely, the differences may give some indication of how science subsequently developed by means of cultural evolution.

Natural Selection for the Origin of Science

Turning to the possible origins of science, it is necessary to distinguish between empirical knowledge based on inductive-deductive reasoning and creative science based on hypothetico-deductive reasoning (see Chapter 8). In hunter-gatherer subsistence, the two most important domains of natural science are those of plant life and animal life.

Gathering plant foods requires much knowledge, but involves little skill once specimens are located, because the immobility of plants reduces the number of variables involved (Silberbauer, 1981). Although a great amount of knowledge is required for gathering plant foods, it is relatively easy to learn and to apply. Hunter-gatherers themselves regard gathering as a monotonous activity (Marshall, 1976). The transition from foraging to gathering involved mainly sociological and technological adaptations. But it may not have required a fundamental change in the nature of the knowledge of plants, or novel forms of scientific reasoning.

Knowledge of edible plants may be gained by means of a trial-and-error accumulation of knowledge based on inductive-deductive reasoning. Knowledge acquired in this way can then be passed on from one generation to the next. Food-gathering does not require imaginative theories to explain plant life or to predict novel facts based on hypothetico-deductive reasoning. As far as I know, it is not possible for a food-gatherer to predict, for example, whether an unknown plant is edible or not, or which plants can be expected in unknown plant communities. Some berries and fruits look good to eat, but are in fact poisonous. Predictions as to where to look for edible plant foods are based on experience and therefore inductive-deductive reasoning seems to be sufficient for the requirements of finding plant food.

While plant foods like berries and fruit may be easily recognized, underground roots may represent the first basic step towards tracking. In a sense a leaf that is visible above ground is a *sign* of an underground root hidden from view. However, apart from the slight delay that it takes to dig out the root, the connection between the visible leaf (the sign) and the hidden root is very direct. This direct association can be learnt from experience and is based on inductive-deductive reasoning. Many other animals, such as baboons, mongooses and gemsbok, also dig out edible roots, so this type of knowledge does not represent a novel evolutionary development in humans.

One interesting example of hypothetico-deductive reasoning applied to plants is their knowledge of Kalahari truffles. After good rains, truffles grow just beneath the surface of the sand underneath low, broad-leafed shrubs near pans. When wet sand dries out a hard crust is formed on the surface. As the truffles grow, they push up the surface of the sand, creating cracks in the crust of the surface.

These distinctive cracks are *signs* of the truffles hidden from view underneath the surface of the sand, so in a sense it involves a very basic form of tracking to find truffles. It is interesting to note that we refer to truffle *hunting*, rather than truffle gathering, and that modern truffle hunters use specially trained pigs or dogs to find them.

!Nate explained to me that when it rains, the leaves collect the rain water, which runs down towards a point from where it drips onto the ground. The rain water is therefore concentrated at specific spots on the ground, and this is where the truffles grow. This hypothesis explains why truffles grow underneath low broad-leafed shrubs after good rains. Understanding why truffles grow when and where they do allows hunter-gatherers to predict when and where they will find them.

However, even before !Nate explained to me why truffles grow underneath these specific shrubs, I successfully found many truffles by simply searching for the distinctive cracks in the surface of the sand near the stems of shrubs. Hunter-gatherers who learnt by trail-and-error (inductive-deductive reasoning) that truffles are associated with specific plants would have been able to find them quite easily.

Knowledge of underground roots and truffles demonstrate continuity between plant food knowledge and the recognition of basic signs based on inductive-deductive reasoning. Searching for roots and truffles may represent the most basic form of simple tracking. But while hunter-gathers may apply hypothetico-deductive reasoning to plants, it is not clear that they *need* to. Once humans developed this ability, they would have applied it to plants as well, but it may not have been a necessity for survival. Plant food gathering therefore does not explain *why* humans needed to evolve the ability to do creative science. Hunter-gatherers seem to know from past seasons when and where to go and look for truffles, so knowledge based on trial-and-error inductive reasoning would have been sufficient. Other animals, which do not practice creative science, are perfectly capable of finding truffles, roots and other plant foods.

While plant life is relatively static, animal life is dynamic, involving a multitude of variables that are continuously changing in real time. Animals are not only highly mobile, living in complex communities, but also actively avoid hunters. Apart from involving knowledge based on direct observation of animal behavior, both simple and systematic tracking also involve knowledge founded on the recognition of signs and the association of particular signs with specific animals and their observed behavior (see Chapters 5 and 6). Since such knowledge is derived from direct observation and association, it is essentially based on inductive-deductive reasoning. The reasoning processes involved in systematic tracking probably do not differ fundamentally from those used by predators who track down their quarry by following a scent trail. The main difference is that, while other predators rely on their sense of smell to follow scent, human systematic trackers must rely mainly on sight to detect signs that are often very complex and sparse. The greater complexity of signs may require more extensive knowledge and skill to recognize, but the mental processes involved may well be the same.

The transition from systematic to speculative tracking, however, may have involved a fundamentally new way of thinking (see Chapters 5 and 6). Apart from information based on direct observations and recognition of signs, speculative tracking also requires the interpretation of signs in terms of creative hypotheses. The speculative tracker creates imaginative reconstructions to explain what the animals were doing, and on this basis makes novel predictions in unique circumstances. Speculative tracking involves a continuous process of conjecture and refutation to deal with complex, dynamic, ever-changing variables. Speculative tracking requires creative hypothetico-deductive reasoning and may therefore explain how, through natural selection, humans evolved the ability to do creative science.

Rare and Infrequent Technological Inventions

Some technological tools may have evolved through trail-and-error, and may therefore not have required creative thinking. It is conceivable that early stone tools evolved over more than a million years in the same way that other species evolved the use of simple tools. Bird nests can be just as intricate and complex as some of the early stone tools. If anything, early stone tools are distinguished by a lack of significant change over considerable periods of time. However, some technological inventions, such as the bow and arrow, would have required creative ingenuity.

Inventions may be rare and infrequent, and once invented can be passed on from one generation to another. Infrequent inventions *require* creativity, but they cannot *explain* how the creative mind evolved in the first place. If a major invention only occurred once in a thousand years, then it is unlikely that that natural selection for inventing technology could be an explanation of how we evolved the creativity required for inventions.

On the other hand, the art of tracking involves creative hypothetico-deductive reasoning on an ongoing basis. Natural selection for the art of tracking would have resulted in the evolution of increasing levels of creative thinking that would have made rare technological inventions possible.

The Cultural Evolution of Science

The similarities between tracking and modern science may suggest how science originated by means of biological evolution. Moreover, the differences between them may give some indication of how science subsequently developed by means of cultural evolution. One of the more obvious ways in which the modern scientist differs from the tracker is that the scientist has access to much more knowledge by means of documentation. He/she may use sophisticated instruments to make highly accurate observations (especially of phenomena that cannot be seen by the naked eye), may use computers to make complicated calculations and may participate in scientific research programmes that involve the collective efforts of large numbers of scientists who may each specialize in different fields of study. As a whole, modern science is obviously much more sophisticated than tracking.

Part of the problem of modern science, however, is that individual scientists must rely to a large extent on documented knowledge. Even though documented scientific knowledge is open to criticism in principle, it is impossible in practice for the individual scientist to appraise critically everything he/she reads. If the scientist attempted to do this, he/she would simply never get down to doing original research. The scientist must therefore rely on the author of a work and on experimental results being repeated by at least some independent researchers. While scientists may have access to a large amount of information, accepting the validity of the information requires to a certain degree an act of faith in others. This has the inherent danger that well-established knowledge may become dogmatic, which may result in irrational beliefs becoming entrenched in science.

A further problem is that computers and instruments are made by humans and are therefore subject to human error. It is impossible in practice for the individual scientist to check for all possible errors involved, including conceptual errors, design errors and manufacturing errors. The use of computers and instruments will then always entail uncertainties that are beyond the control of the individual scientist. Although documentation, the use of computers and instruments and the large-scale of modern collective research have considerable advantages, they also introduce new uncertainties. The individual scientist's access to a large body of knowledge does not necessarily make it easier to reach a rational decision. The tracker, by contrast, is in direct contact with nature. Ideas and interpretations are continuously tested in nature itself. Signs are observed directly (without interference of observational instruments), and hypotheses may predict further observations in the immediate vicinity.

Hypothetical interpretations are therefore open to direct criticism by any individual tracker.

A characteristic feature of an advanced science such as modern physics is the complex hierarchical structure of hypotheses and the fact that the chain of reasoning from observational "facts" to the most general hypotheses may be very long (Holton, 1973). In contrast, the art of tracking does not have a complex hierarchical structure and the chain of reasoning from observation to the most basic hypotheses is fairly short. Yet the lack of a formal hierarchical structure in tracking allows for a greater multitude of basic hypotheses. Furthermore, the hierarchical structure of an advanced science also makes it less accessible to people who do not have sufficient background knowledge. This situation gives rise to an authoritarian elitism in modern science.

None of the differences between modern science and the art of tracking require a fundamentally new way of thinking. The differences are mainly technological and sociological. Although modern science is much more sophisticated, it has grown mainly quantitatively, not qualitatively. The creative scientific process itself has not changed and the intellectual abilities required for tracking and modern science are essentially the same.

Tracking represents science in its most basic form. As a collective research programme of a relatively small number of interacting individuals, the art of tracking would not have been as sophisticated as the accumulated corpus of modern physics, since modern physics is the result of the collective efforts of a large number of some of the world's best intellects and has been developed over a long period of time. Yet the human brain has probably not changed significantly since the appearance of modern hunter-gatherers: some trackers in the past probably were, and perhaps today are, just as ingenious as the most ingenious modern mathematicians and physicists.

In principle, there is no limit to the degree of sophistication to which a particularly ingenious individual could develop the art of tracking. In practice, however, the tracker's knowledge is limited by his/her own observations of nature and the information transmitted through oral tradition. In contrast the modern scientist has relatively easy access to greater body of knowledge available in libraries and databases, uses sophisticated instruments to make highly accurate observations, or computers to make complex calculations, and participates in scientific research programmes that involve the collective efforts of large numbers of scientists who individually specializes in different fields of study.

I would argue that the differences between the art of tracking and modern science are mainly technological and sociological. Fundamentally they involve the same reasoning processes and require the same intellectual abilities. The modern scientist may know much more than the tracker, but he/she does not necessarily understand nature any better than the intelligent hunter-gatherer. What the expert tracker lacks in quantity of knowledge (compared to the modern scientist), he/she may well make up for in subtlety and refinement. The intelligent hunter-gatherer may be just as rational in his/her understanding of nature as the intelligent modern scientist. Conversely, the intelligent modern scientist may be just as irrational as the intelligent hunter-gatherer. One of the paradoxes of progress is that, contrary to expectation, the growth of our knowledge about nature has not made it easier to reach rational decisions (Stent, 1978).

Cultural Relativism

I should emphasize that I am not advocating cultural relativism. The success of a scientific theory depends on how well it is correlated with an objective reality that is independent of the human observer's point of view. Some theories are better than others and science does make progress.

Science is not equivalent to mythology or fiction and we cannot, as Bruno Latour suggests, "abolish the distinction between science and fiction"

(Woolgar, 1988, p. 166). Science enables us to get in touch with objective reality in a way that mythology and fiction does not. There may be continuity between science and mythology (see *Mythology and Religion*, Chapter 5), but science is not mythology. When you look at a rainbow, there is continuity from red, to orange, yellow, green through to blue, but red is not blue.

On the surface modern science may seem to be "incommensurable" with indigenous knowledge, in the sense that Kuhn (1962) have argued that theories before and after a "scientific revolution" were "incommensurable." Even though Relativity Theory uses the "field" metaphor to describe gravitation, which may seem to be incommensurable with Newton's use of the "force" metaphor, Einstein regarded his theory as "a modification" and therefore continuous with a long tradition going back centuries (Holton, 1986). While Newton's theory was still used to put a man on the Moon, a practical implication of Relativity Theory is the calibration of clocks in orbiting satellites required to maintain the accuracy of GPS which many people today use in their daily lives to navigate road maps (Rees, 2011).

Indigenous knowledge may use metaphors that may on the surface seem to be incommensurable with those used in modern science (just as Einstein's theory uses metaphors that may seem to be incommensurable with Newton's theory), but indigenous knowledge systems provided a sufficiently reliable correlation with reality to secure the survival of indigenous communities.

On the other hand, we cannot naively assume that indigenous knowledge was somehow the result of a magical "wisdom of the elders" that guaranteed "truth." Just as many modern scientific theories may simply be wrong, much of indigenous knowledge may have been wrong. Science does make progress over time, adopting new metaphors to refine our understanding of reality. Conversely, cultures may go into decline when scientific knowledge is undermined by irrational belief systems.

As an aside, it should be noted that cultural relativism has nothing to do with Einstein's Relativity Theory. In fact Einstein would have preferred to use the term "Invariantentheorie," to reflect his hypothesis that the laws of physics are invariant, not relative, to the frame of reference (Holton, 1986) (see also Holton, 1973, p380 on the "abuse of relativity theory in many fields.") The term "Invariant Theory," rather than "Relativity Theory," may well have avoided much of the confusion caused by the notion that "everything is relative."

Conceptual Discontinuities

Gerald Holton (1986) points out that the development of modern Western thought has been marked by the elimination of conceptual discontinuities. These included Copernicus's view that the earth, and therefore man, was not the center of the universe. Another was Darwin's theory that denied man's privileged position of having been specially created, and relegated him to a descent from the animal world. Others include perceived discontinuities between space and time, between energy and matter, between man and machine. In each case, a culture shock resulted from the discovery that such barriers did not exist, that discontinuity gave way to a continuum.

Edward O. Wilson (1998) maintains that today the greatest divide within humanity is not between races, or religions, or even between the literate and illiterate. It is, he says, the chasm that separates scientific from prescientific cultures.

I would argue that there may have been no discontinuous revolutions in the history of science. Rather, science involved a continuous process of evolution growing logirithmicly for more than a hundred thousand years, going back to prescientific empirical knowledge possibly as far back as two million years ago.

In addition, there may be no discontinuous divide that separates "scientific" from "prescientific" cultures in the world today. There is continuity from formal, professional Western science, varying degrees of citizen involvement in science, through to "indigenous knowledge" practiced by recent hunter-gatherers (see Chapters 10 and 11). Western science does not hold a distinctly privileged position in human history. It is the culmination of an evolutionary process that is continuous both in time and across the variety of modern human cultures.

Recognizing the continuity of science through time and across cultures means that science should become an inherent part of our cultural heritage. Not only do we need to democratize science within specific cultures and within democratic countries, but globally across nations and cultures. Science is as much an innate ability of humans as is language, storytelling, poetry, music and art - an indispensable part of what makes us human.

8

The Scientific Imagination

To develop an explanation of how science evolved, we need to have some understanding of what we mean by the term "science." In this book I will make a clear distinction between "empirical knowledge" and "creative science." I will look at how some scientists think when they engage in scientific reasoning and the views of various scientists and philosophers of science. I will point out the similarities between the art of tracking and modern science, with particular reference to modern physics.

Novel Predictions in Tracking

Perhaps the most significant feature of hypothetico-deductive reasoning in science is that a hypothesis may enable the scientist to predict novel facts that would not otherwise have been known (Lakatos, 1978a).

A simple example of how hypothetico-deductive scientific reasoning may result in the prediction of novel facts in tracking is illustrated by a set of caracal tracks I found at Cape Point near Cape Town where I live. The caracal is a nocturnal wild cat and is hardly ever seen during the day on the outskirts of a city where it may be disturbed by humans and dogs.

Looking at the tracks I could visualize how the caracal was walking when it turned and pounced towards the left, twisted around and jumped back towards the right. There were no signs or tracks of the animal it was pouncing at. Initially I thought *of two explanations. At first I thought it could not have pounced at a bird, because it pounced twice, and if the bird flew away, why would it pounce a second time? So I thought the fact that it pounced twice indicated that a mouse ran from the first pounce landing position to the second pounce landing position. But there were no sign of mouse tracks, so I thought that maybe the wet sand was hard enough that the mouse tracks did not show, or that it was maybe a little shrew. But neither hypothesis made me feel confident that it was the right explanation, leaving me feeling uneasy - it was a bit of a mystery to me.*

Fig. 14: The second set of bounding gait footprints left deep impressions. (Photo: Steven Pinker)

Novel Solution

The next morning I thought of a novel solution. Two things made me feel uneasy: firstly, I could not find any sign of mouse tracks, yet even the smallest mouse should have left faint signs of its sharp claws digging into the sand as it tried to get away from the caracal; secondly, the second time the caracal jumped (after twisting around), the bounding gait footprints left deep impressions (Fig.14), yet the stride length to the point where it landed was very short.

What I think must have happened is that it tried to pounce on a small bird sitting on the ground. The bird flew up in the direction of the second set of "pounce tracks," so the caracal twisted around and leapt straight up into the air to catch the bird in mid-air. This would explain why the bounding tracks for the second leap left deep imprints (its feet was pushing down into the ground, not backwards) and why the stride length was so short (it went straight up and down). It would also explain why I could not find any mouse tracks or any other tracks. The tracks of the little bird, where it was sitting, would have been obliterated by the tracks of the caracal when it tried to pounce on it the first time.

I then remembered that a few years before a colleague of mine, Adriaan Louw, told me that he had seen a serval leap up and catch a bird in mid-air, but this was something I assumed a caracal would not be able to do. The serval is a very slender, agile cat, while the caracal is a much heavier, stocky animal. Just as the slender cheetah is a much faster animal than the heavier, stocky leopard, I assumed that the slender serval would be much faster than the stocky caracal. So the thought that a caracal could be fast enough to catch a bird in mid-air never occurred to me.

I did not initially think of this explanation because at the time I did not know that a caracal could leap up and catch a bird in mid-air. In terms of my own experience at the time, this was a new behavior that I did not know of. As with any set of data that creates a puzzle that do not fit your preconceived expectations, your subconscious need to work on it to create a new hypothesis – I had to "sleep on it" before thinking of a solution the next morning, resulting in an "aha moment." Even though the memory of the serval account seemed like an after-thought that indirectly substantiated my interpretation of the caracal tracks, it probably did play a role subconsciously in finding a solution while I was asleep. In mathematics and science, the creation of a hypothesis often requires a subconscious period of incubation preceding a sudden illumination (Hadamard, 1945). Since the caracal is nocturnal, it is unlikely that I would ever observe this behavior. However, creating a hypothetical explanation of the tracks enabled me to predict a novel fact about the caracal's behavior.

The "novelty" of my prediction needs to be qualified. Subsequent literature research confirmed that the caracal is in fact fast enough to leap up to catch birds in mid-air (Dorst and Dandelot, 1970) and that their speed surpasses that of most cats (Pocock, 1939). Although this was therefore not strictly a novel prediction, since it has been documented in the literature, the fact that it was new in terms of my own experience does illustrate how a tracker can predict novel facts by creating a hypothesis to explain tracks. A non-literate Kalahari tracker with no access to the literature could conceive the same hypothesis and make the same novel prediction, but it is not possible to "observe" the thought processes of a traditional tracker. Even when you interview them, the more subtle aspects of their thought processes are lost in translation. My own experience is therefore the only way that I can analyze the thought processes of a tracker.

New Metaphor

My existing understanding of caracal behavior could not explain the tracks. As I projected myself into the tracks, I visualized what happened in terms of what I would have done if I were the caracal. However, since I have never seen a caracal leap into the air, I had no conception of how fast it could be. The speed of a caracal fell outside my own experience. To solve the contradictory evidence of the tracks therefore required visualizing something I did not know was possible. I had assumed that the strongly built caracal could not be fast enough to catch a flying bird in mid-air, so the thought did not immediately occur to me. The solution required a new metaphor, to visualize a caracal "shooting up" into the air. Something like an arrow being released from a bow, rather than "jumping" or "leaping" as I would visualize myself "jumping" or "leaping" if I were the cat. The "shooting up" into the air would have to be unimaginably faster than I would be able to imagine myself leaping up into the air. Something a human is not capable of.

New Mental Category

In addition, the solution also involved creating a simpler, deeper unity in how I perceived different cats. I assumed that the slender serval and the slender cheetah belong to a group of cats that are much faster than the group of heavier, stocky cats, like caracals and leopards. This is reflected in the shape of their tracks. Serval have narrow, slender tracks, while caracals have broader tracks (see Fig. 15, page 154). So while the serval was fast enough to catch a bird in mid-air, I assumed that the caracal was not fast enough. The solution required the creation of a new mental category that grouped all the cats that can *leap* fast enough to catch birds in mid-air, irrespective of how fast they can *run*, thereby creating a deeper underlying unity in my mental classification of cats.

I subsequently asked Adriaan (who reported the serval incident to me) whether he knew of any sightings of caracal catching birds in mid-air. He did not, but while working on a lion research project in the Kruger National Park he did see a lioness catch a bird in mid-air. Recently, while I was tracking a lion I found evidence that it had caught a guinea fowl (freshly scattered clumps of feathers on the trail), but it was not clear if it was caught on the ground or in the air. However, if lions (the heaviest of all the cats) can catch birds in mid-air, then it is possible that *all* cats can do so (although I have no evidence that leopards, cheetahs, African wild cats or Small Spotted cats have been observed to do so). From a single anecdotal observation assumed to apply to only one species, a generalization was formed that applies to all cats. This is an example of an underlying "law like" generality that trackers may use to explain tracks.

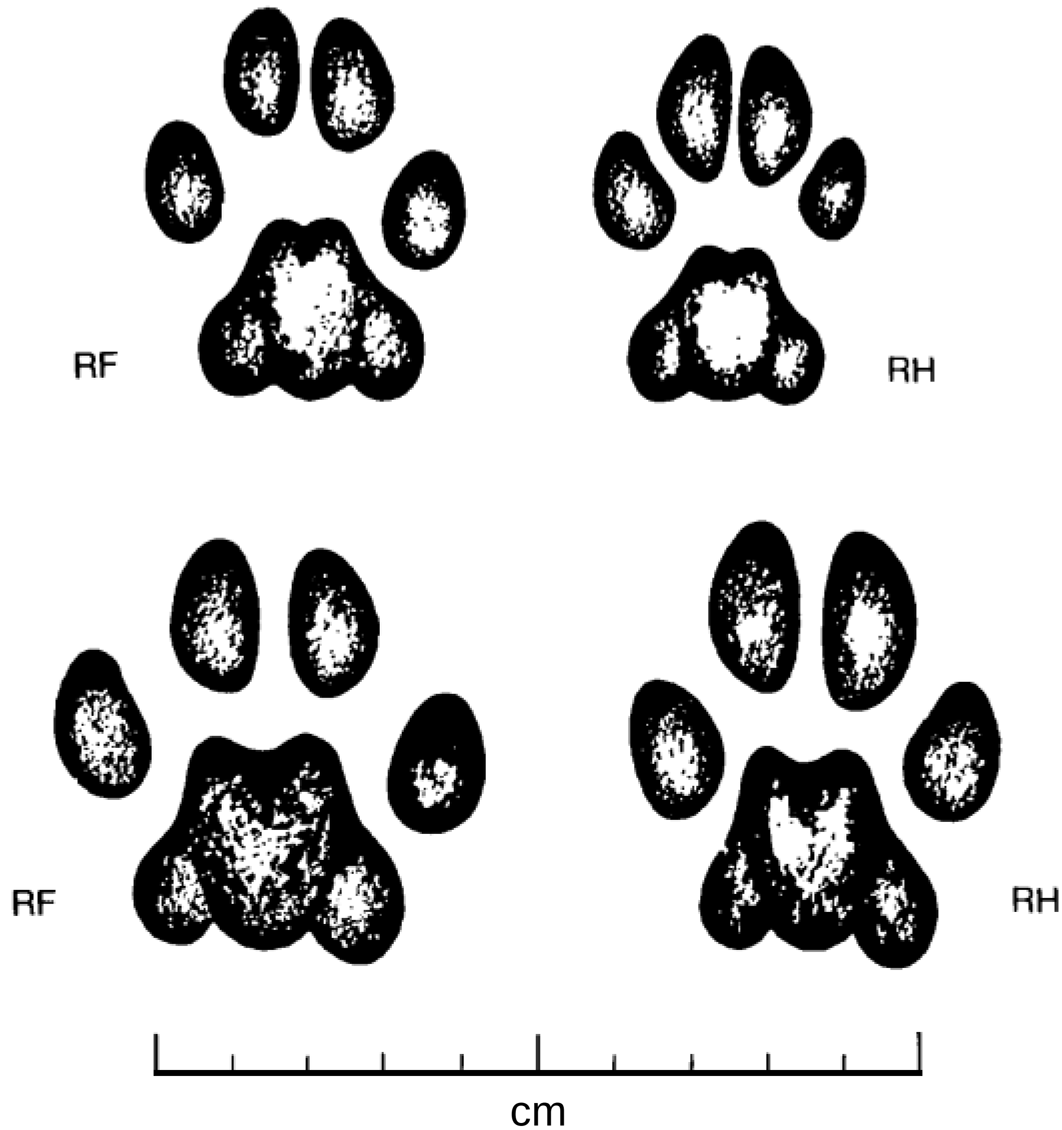


Fig 15: Right fore and right hind tracks of serval (top) and caracal (bottom)

With hindsight it may seem an obvious solution that *all* cats should be able to leap fast, but my existing mental categories (light & slender = fast; heavy & stocky = slow) created a "mental block," so at the time it was not obvious to me at all. My existing mental categories *excluded* this possibility. This assumption also had its origins in anthropomorphic projection. I assumed that stocky cats are slower than slender cats, because (by analogy) heavy, stocky humans are slower than light, slender humans. The novelty of the solution not only required visualizing a new activity (not known for the caracal, although by analogy known for the serval) that explained the caracal tracks, but also creating a new underlying mental category that made it possible. This example illustrates how the creation of a new metaphor and a deeper underlying unity allows a tracker to solve an apparent paradox or contradiction in tracking.

It is perhaps interesting to note that the new metaphor resulted in the creation of a similarity (at a deeper level) where there was previously perceived to be a dissimilarity. Aristotle said in *On Poetics:* "But the greatest thing by far is to be a master of metaphor. It is the one thing that cannot be learnt from others; and it is also a sign of genius, since a good metaphor implies an intuitive perception of the similarity in dissimilars."

Another example of "law like" deeper underlying generalities is the explanation given by a !Xõ and /Gwi trackers of the different shapes of the tracks of hoofed antelope (see *Underlying Simplicity, Symmetry and Unity*, page 90, Chapter 5).

Unifying "Law-Like" Generalities in Tracking

The ability of trackers to solve apparent contradictions may explain how humans evolved the ability to solve paradoxes in modern science. The most fundamental unifying principle in tracking is the assumption that "all animals are like people" (see Chapter 5) and that a human tracker can therefore predict the behavior of animals by interpreting tracks and signs. Novel predictions are made when the tracker discovers ways in which animals are *different* from humans, but also involves the creation of new underlying similarities that unify different animals in ways that was previously excluded by existing categories.

The young tracker starts out by assuming that animals are in many ways like people. As the tracker discovers more and more about an animal over time, the highly anthropomorphic model of animal behavior grows closer and closer to what the animal is really like. But no matter how sophisticated the tracker's model of animal behavior becomes, it will always retain an element of anthropomorphic projection, since hypotheses are products of the human imagination. The tracker will always ask: "What would I do if I were that animal?"

The assumption that "animals are like people" and that human trackers can therefore predict the behavior of animals can be translated to modern science as the assumption that the human mind can make novel predictions about reality. Science is therefore limited to those aspects of reality that can be predicted by the human mind. There may well be aspects of reality that we do not know about and may never know about, since we can only make empirical observations that can be predicted by the human mind and perceived by human senses. Observations perceived by humans are then explained in terms of metaphors that capture the underlying relationships. Ultimately scientific hypotheses are verbalized using metaphors that the human mind can identify with. At the most fundamental level the human mind will always depend on anthropomorphic projections.

The hypothesis to explain the caracal tracks involved three components of the art of scientific imagination highlighted by Gerald Holton (1996), namely visual imagination, the use of analogy and the thematic imagination (see section on *Thematic Presuppositions,* page 169). These three components of the scientific imagination can be found in the way Einstein developed his ideas for Relativity Theory.

Novel Predictions in Modern Science

In 1864 James Clerk Maxwell's theory of electrodynamics unified electricity, magnetism and light – phenomena that were believed to be separate and distinct from one another. Maxwell's theory essentially created a deeper underlying unity in nature. Maxwell's theory also predicted the existence of radio waves. This prediction enabled Heinrich

Hertz in 1886 to build an instrument (the Hertz antenna receiver, a radio) that could produce and observe radio waves. But to observe radio waves the instrument had to translate radio signals (that cannot be perceived by humans) into visual or auditory signals (that can be perceived by humans).

Maxwell's theory also predicted that light should be propagated in a vacuum with a constant velocity, *c*, irrespective of the velocity of its source. The apparent significance of *c*, the constant which occurs in the laws of electrodynamics, is as a quantity which has a fixed value with respect to a uniquely preferred frame of reference, namely the ether, the "medium" through which light was believed to propagate (Angel, 1980).

By 1898 ten experiments failed to detect any evidence of the supposed existence of the ether, including the famous Michelson-Morley experiment (Holton, 1973). The constant velocity of light created a paradox that could not be resolved, and by the end of the nineteenth century physics found itself in a profound conceptual crisis (Angel, 1980). This crisis was resolved in 1905 with the publication of Einstein's theory of special relativity.

The Origins of Special Relativity

Contrary to the long-held belief in the crucial role of the Michelson-Morley experiment, the influence of this experiment on Einstein was small and indirect (Holton, 1973). The experimental results which had influenced him most were the observations on stellar aberration and Fizeau's measurements on the speed of light in moving water.

To explain why the earth did not appear to move relative to the ether, it was proposed that perhaps the ether is locally "dragged" by the earth. This, however, was in conflict with the observation of stellar aberration first made by James Bradley in 1728, which provided evidence for the motion of the earth around the sun (Gasiorowicz, 1979). Due to the motion of the earth around the sun, the apparent positions of stars are observed to move in circular orbits of very small angular diameter. This is the same effect as that which causes a vertical shower of rain to appear to a moving observer as falling at an angle. The astronomical effect would not be present if a light ray were to travel with constant velocity with respect to the ether frame and if that frame were fixed with respect to the earth (Eisberg, 1961).

In 1853 Armand Fizeau had measured the velocity of light in a column of rapidly flowing water. If the water were to drag the ether frame with it, the observed velocity would just be the sum of the velocity of light in stationary water and the velocity of the water. The result was fully accounted for by the electromagnetic theory of Maxwell, without introducing the ether drag hypothesis (Eisberg, 1961).

These results, according to Einstein, were enough to originate the theory of Relativity. The essential evidence that made it possible to formulate the theory of Relativity was therefore known for 40 years. However, Einstein subsequently realized that the puzzling result of the Michelson-Morley experiment could be used to make it easier for other physicists to accept Relativity theory (Holton, 1973).

In the introduction to his paper on his theory of special relativity, "On the Electrodynamics of Moving Bodies," Einstein wrote that: "It is known that Maxwell's electrodynamics… when applied to moving bodies, leads to asymmetries which do not appear to be inherent in the phenomena. Take, for example, the reciprocal electrodynamic action of a magnet and a conductor. The observable phenomenon here depends only on the relative motion of the conductor and the magnet, whereas the customary view draws a sharp distinction between the two cases in which either the one or the other of these bodies is in motion… Examples of this sort, together with the unsuccessful attempts to discover any motion of the earth relatively to the 'light medium,' suggest that the phenomena of electrodynamics as well as mechanics possess no properties corresponding to the idea of absolute rest… and also introduce another postulate…

namely that light is always propagated in empty space with a definite velocity *c* which is independent of the state of motion of the emitting body… the introduction of a ‘luminiferous ether’ will prove to be superfluous inasmuch as the view here developed will not require an ‘absolutely stationary space’…” (Einstein, 1905).

What Einstein asked is why are there in Maxwell’s theory one equation for finding the electromotive force generated in a moving conductor when it goes past a stationary magnet, and another equation when the conductor is stationary and the magnet is moving? After all, it is only the relative motion between conductor and magnet that counts. By extending the principle of relativity which, since Newton, was never doubted in mechanics, by analogy to electrodynamics, Einstein argued that there was no such a thing as “absolute motion” and that there was therefore no need to assume the existence of the ether (Holton, 1973).

Deeper Underlying Unity

By applying the principle of relativity not only to mechanics, but by analogy also to electrodynamics, Einstein found a deeper symmetry and universality in the operations of nature. It is this deeper underlying unity, involving elements of the thematic imagination, rather than the available experimental evidence, that was the primary impetus that led Einstein to solve the apparent paradox (Holton, 1973).

It is significant that Henri Poincaré came very close to solving this problem. Poincaré had written a philosophical book, *Science and Hypothesis* (Poincaré, 1901), which Einstein studied, that explored the foundations of knowledge and criticized the Newtonian notions of absolute space and time. The theories created by Poincaré and Einstein were operationally equivalent, with identical experimental consequences, but with one crucial difference. The wave theory of light was based on the idea of the “luminiferous ether,” a metaphor for the medium through which electromagnetic waves were believed to propagate. Poincaré was unable to let go of the ether metaphor. By rejecting the ether metaphor, Einstein was able to create a theory that was more simple and elegant (Dyson, 2006).

Einstein described what he regarded to be the origins of relativity theory: "… I despaired of the possibility of discovering the true laws by means of constructive efforts based on known facts… I came to the conviction that only the discovery of a universal formal principle could lead us to assured results… After ten years of reflection such a principle resulted from a paradox upon which I had already hit at the age of sixteen: If I pursue a beam of light with the velocity *c* (velocity of light in a vacuum), I should observe such a beam of light as a spatially oscillating electromagnetic field at rest. However, there seems to be no such thing, whether on the basis of experience or according to Maxwell's equations." In addition to his first postulate of invariance, Einstein proposed a second postulate: "…that light is always propagated in empty space with a definite velocity *c* which is independent of the state of motion of the emitting body…" Only by postulating the principles of relativity was this paradox resolved (Holton, 1973).

In addition to the first postulate, that the laws of physics, including electrodynamics, are invariant for all observers, Einstein therefore proposed a second postulate, namely that light is always propagated in empty space with a definite velocity *c* which is independent of the state of motion of the emitting body. The implication of these postulates are that time and distance are relative, not absolute.

In theoretical physics a theory is built on fundamental concepts and postulates, or laws, from which conclusions can be deduced. Einstein explained that: "There is no logical path to these laws; only intuition, resting on a sympathetic understanding of experience"… These fundamental concepts and principles are "free inventions of the human intellect" (Einstein, 1954).

Anthropomorphic Representation

The process of subjective simulation, whereby we simulate subjectively the events around us, is essentially a predictive attitude. When a scientist is interested in a given situation, he/she tries to simulate the situation subjectively to achieve a form of internal representation (Monod, 1975). In nuclear physics, the experimenter's preconceived image of the process under investigation determines the outcome of the observations. This image is a symbolic, anthropomorphic representation of the basically inconceivable atomic processes (Deutsch, 1959).

The creative scientific imagination may function by evoking potential or imagined sense impressions. Some physicists think of an atom by evoking a visual image of what they would see if the atomic model existed on a scale accessible to sense impressions. At the same time the physicist realizes that it is in principle inaccessible to direct sensory perception (Deutsch, 1959). When a scientist has such a visual image, the nature of the seeing or sensing is almost as though he/she felt like the object being visualized (Walkup, 1967).

Nobel laureate Jacques Monod (1975) maintained that in thinking about a phenomenon they are interested in, some physicists, even in highly abstract theoretical physics, may more or less identify themselves with, for example, a nuclear particle and may even ask: "What would I do if I were that particle?" And mathematician Paul Olum suspected that when Nobel laureate Richard Feynman wanted to know what an electron would do under given circumstances he asked himself: "If I were an electron, what would I do?" (Gleick, 1992:142).

Einstein's thought experiment involved projecting himself into the position of a light beam. In his imagination he visualized how he "pursued a beam of light" very much in the way a tracker would project himself into an animal in order to "pursue the animal" in his imagination. He engaged in a "sympathetic understanding" of what it would be like to be a light beam. What Einstein described is essentially a form of anthropomorphic projection, which had its origins in the art of tracking.

This paradox becomes more striking as science becomes more sophisticated. In any advanced science even the simplest observation involves a formidable apparatus of theory. The ratio of signal to noise is extremely small in the laboratory, where the energy, the size and period of persistence of the phenomena studied are minute compared to the other attendant data. Observations in nuclear physics can only be understood and used if, from the very beginning, the scientist has a well-structured image of the actual connections between the events taking place. Thus modern science is not entirely depersonalized, cold and abstract. Rather, the nuclear physicist may project human relationships into his/her equipment and data. The symbolic power of useful scientific concepts lies in the fact that many of these concepts have been importing anthropomorphic projections from the world of human drama (Holton, 1973).

In the art of tracking the anthropomorphic way of thinking arises from the tracker's need to identify him/herself with the animal in order to anticipate and predict its movements. The tracker must visualize what it would be like to be that animal within that particular environmental context. In doing this the tracker must ask: "What would I have done if I was that animal?" To be able to do this the tracker must know the animal very well. But in the process the tracker superimposes his/her own way of thinking onto that of the animal, thereby creating a model of animal behavior in which the animal is understood to have certain human characteristics.

The creation of such a preconceived image of what the animal was doing is particularly important in difficult tracking conditions. In conditions where signs are sparse, the information content of signs are very little, and where there are many proximate signs that could confuse the tracker (i.e. where the ratio of signal to noise is very small – see page 60), the tracker needs a preconceived image to recognize the relevant signs and to establish the connections between them.

Considering the role of the anthropomorphic way of thinking in science, it is by no means obvious why a physicist should think in such a way. On the contrary, it would appear to be a rather paradoxical way to understand highly abstract physical concepts. On the other hand, it is quite clear why a tracker should think in such a way. This may well suggest that the creative scientific imagination had its origin in the evolution of the art of tracking.

Anthropomorphic projection in science implies that science can never attain the ideal of an "objective knowledge." Scientific understanding will always contain a subjective element that is a product of the human imagination. At the most basic level, the human mind must resort to metaphors from human experience. We project human experience into reality. However, anthropomorphism does not deny that objective reality exists – only that our perception of reality will always contain a subjective element. This subjective element may be so subtle that many scientists would deny any subjectivity in their scientific work. The ideal of scientific objectivity has had such a strong ideological influence in Western science that it is simply assumed to be valid.

A characteristic feature of the scientific knowledge of hunter-gatherers is the anthropomorphic nature of their models of animal behaviour. This anthropomorphic element is not necessarily unscientific. On the contrary, it may well be a result of the creative scientific imagination. Indeed, anthropomorphic projection has been noted as an essential and important element in scientific work (Holton, 1973). To imagine and speak about the world invisible to us, we populate it with anthropomorphic and everyday concepts, almost by necessity (Holton, 1996).

Spatial Visualization

In Chapter 6 (page 122) I argued that the human visual imagination may have had its origin in the interpretation of tracks and signs.

Visual imagery plays an important role in scientific creativity and Einstein is one of the more noteworthy examples of the importance of visual thinking. Visual intuition was crucial for all of Einstein's great insights, such as imagining himself traveling at the speed of light. Most of his visual thought experiments occurred in the twenty-year period between 1895 and 1915, the period of his singular creative genius. In contrast, the lack of creativity in Einstein's later life corresponded to his decline in his use of visual imagery (Feist, 2006). Richard Feynman pointed out that Einstein stopped thinking in concrete physical images and became a manipulator of equations (Gleick, 1992).

Spatial visualization ability has a unique role in the development of creativity. Spatial ability not only plays a unique role in assimilating and utilizing pre-existing knowledge, but also plays a unique role in developing new knowledge (Kell, et al, 2013). It is skill in spatial ability that determines how far one will progress in science and technology (Gardner, 1983). A study conducted over 20 years have shown that intellectually talented adolescents with stronger spatial ability relative to verbal ability were more likely to be found in engineering and computer science-mathematical fields (Shea, et al, 2001).

Benefits of Relativity Theory to Kalahari Trackers

In the previous sections we looked at how Einstein's thought processes may have originated in the way trackers think. As an aside, it is interesting to note that Einstein's relativity theory has made a practical contribution to the development of modern tracking that has been of direct benefit to trackers in the Kalahari. The accuracy of the Global Positioning Satellites

(GPS) used in SatNav systems would be fatally degraded if proper allowance wasn't made for the slight difference between the clock rates on Earth and those in orbit that is predicted by relativity theory (Rees, 2011). Kalahari trackers using the CyberTracker to gather data (see Chapter 10) therefore benefit directly from Einstein's theory.

The Logic of Science

In this book I will use the term "empirical knowledge" to refer to knowledge based on inductive-deductive reasoning, and the term "creative science" to refer to scientific knowledge based on hypothetico-deductive reasoning.

An example of inductive-deductive reasoning would be: Based on past experience, we know that the sun always comes up in the east in the morning. Therefore we can predict that the sun will come up in the east tomorrow morning. We use induction to make a generalization (the sun always comes up in the east every day), which we then use to deduce a prediction (therefore the sun will come up in the east tomorrow morning). Inductive-deductive reasoning does not explain why the sun comes up in the east every morning and cannot make novel predictions.

An example of hypothetico-deductive reasoning would be: A philosopher living in ancient Greece may have come up with a hypothesis that the sun appears to come up in the east every morning because the Earth revolves around its axis. The philosopher would then have been able to predict that the sun will always appear to come up in the east every morning. Hypothetico-deductive reasoning explains why the sun appears to come up in the east every morning. Furthermore, this hypothesis would have enabled the philosopher to make a *novel prediction* – that if you traveled to the North Pole, the sun will *not* appear to come up every morning.

Inductive-Deductive Reasoning

Inductive-deductive reasoning involves a process in which the premises are obtained by generalizing observed particulars. These are then assumed to be representative of universal principles. This initial process of induction starts with the assumption that statements about a number of individual animals, for example, can lead to generalizations about a species of which they are members. Such generalizations are then used as premises for the deduction of statements about particular observations. A more concrete example would be the way tracks are identified as that of an animal belonging to a particular species.

The inductive stage of the argument may be as follows: all the members of a particular species that have been observed produced tracks which had certain characteristics, and no member of that species had been observed to produce tracks that did not have those characteristics. We therefore assume that all members of that species produce tracks which have those specific characteristics. Furthermore, no animal which did not belong to that particular species have been observed to produce tracks which had exactly the same characteristics. We therefore assume that only members of the particular species in question produce tracks which have those specific characteristics.

The deductive stage of the argument would then be as follows: we assume that all members of a particular species and only members of that particular species produce tracks which have specific characteristics. We conclude, therefore, that any particular track observed to have those specific characteristics would have been produced by a member of that species.

In the inductive stage, generalizations are based on a limited number of particular observations, while in the deductive stage the identity of a particular track is deduced from assumed general premises. In the deductive stage, the conclusions follow logically from the given premises.

The premises, however, have been reached by a process of induction which involved assumptions that cannot be logically justified (see below). Since the truth of the premises cannot be established logically, it follows that the truth of the conclusions cannot be established by the premises from which they are deduced. Although particular conclusions may be confirmed empirically, the truth of the conclusions does not imply that the premises are true.

Apart from the identity of tracks, other generalizations may be used as premises to distinguish special features of tracks, such as those indicating the sex, age, size or mass of the animal, or characteristic markings that indicate specific gaits or activities. Generalisations about habits, preferred habitat, sociability, feeding patterns, and other aspects of the behaviour of animals may also be assumed premises from which to make certain deductions in the interpretation of tracks.

In this book the meaning of "induction" is limited to induction by simple enumeration. A typical induction by simple enumeration has the form:

a(1) has the property P
a(2) has the property P
a(3) has the property P
....
a(n) has the property P

All a's have the property P

In an inductive argument by simple enumeration, the premises and conclusions contain the same descriptive terms (Losee, 1972). It is therefore simply a process of empirical generalization. Empirical generalizations constitute no progress in science, since they may only lead to the discovery of facts similar to those already known (Lakatos, 1978a).

Inductive-deductive reasoning is based on direct observations and ordinarily recognizes apparent regularities in nature. Inductive knowledge, therefore, is based on a trial-and-error accumulation of facts and generalizations derived by simple enumeration of instances. It does not explain observations and cannot result in the prediction of novel facts. It can only predict particular observations similar to those that have been observed in the past. Predictions are therefore simply based on experience.

Hypothetico-Deductive Reasoning

In contrast to inductive-deductive reasoning, hypothetico-deductive reasoning involves the explanation of observations in terms of hypothetical causes. The hypotheses may be used as premises in conjunction with initial conditions from which certain implications may be deduced. Some of the implications deduced in such a way may include novel predictions. Hypothetico-deductive reasoning is an exploratory dialogue between the imaginative and the critical, which alternate and interact. A hypothesis is formed by a process which is not illogical but non-logical, i.e. outside logic. But once a hypothesis has been formed it can be exposed to criticism (Medawar, 1969).

A characteristic feature of a theoretical science is that it explains the visible world by a postulated invisible world. So in physics visible matter is explained by hypotheses about an invisible structure which is too small to be seen (Popper, 1963). Similarly, in the art of tracking, visible tracks and signs are explained in terms of invisible activities. A sympathetic understanding of animal behaviour (see *Novel Predictions in Tracking*) enables the tracker to visualize what the animal may have been doing in order to create hypotheses that explain how visible signs were made and how they are connected. Visible signs are therefore connected by invisible processes. These postulated connections are inventions of the tracker's imagination. Although these hypothetical connections cannot be seen, the conclusions that can be deduced from them enables the tracker to anticipate and predict visible signs.

A theoretical science such as physics is analogous to tracking in the sense that observable properties of the visible world may be regarded as *signs* of invisible structures or processes. The *force* of gravity (in Newton's theory), or alternatively the gravitational *field* (in Einstein's theory), or more recently, the Higgs Boson cannot actually be seen. Its postulated existence is only indicated by observable effects on bodies similar to those that such a force (or field) would have on bodies. Nuclear particles cannot be seen. Physicists can only see *signs*, such as "particle tracks," that correspond to those that would be made by hypothetical particles.

In the process of tracking down an animal, a tracker must explain tracks in order to anticipate and predict where to find tracks further ahead, and eventually where to find the animal itself (before the tracker is seen by the animal). If the anticipation and prediction of tracks is simply based on previous experience (i.e. based on inductive-deductive reasoning), it does not involve the prediction of novel facts. But when a tracker is confronted with a set of tracks and signs that cannot be explained in terms of previous experience, a new hypothesis must be created. If successful, such a hypothesis may enable the tracker to predict novel facts about the animal's behaviour. Within the context of tracking, hypothetico-deductive reasoning may enable the tracker to acquire new knowledge that would not otherwise have been known.

Hypothetico-deductive reasoning is a constant interplay or interaction between hypotheses and the logical consequences they give rise to. In practice scientists also tend to develop multiple working hypotheses (Chamberlain, 1890). Deduction guarantees that if hypotheses are true, then the inferences drawn from them will also be true. But even if these logical conclusions are true, it does not follow that the hypotheses which gave rise to them are true, since false hypotheses can lead to true conclusions (Medawar, 1969). Hypothetico-deductive reasoning may be described as a cybernetic process, in the sense that continuous adjustment and reformulation of hypotheses is brought about through a process of negative feedback from their deductive consequences. If their logical consequences are true, hypotheses need not be altered, but if they are false, corrections have to be made (Medawar, 1967).

The art of tracking may be regarded as a continuous cybernetic process. In each individual hunt, working hypotheses are created to reconstruct the animal's activities in order to predict where it was going. Such hypotheses are continuously revised as new information from tracks confirms or contradicts the tracker's expectations. Even though the tracker's knowledge of animal behaviour is based on experience gained from previous hunts, each hunt may result in new knowledge and revisions of previous knowledge. In the same fashion the collective research programme of a group of interacting trackers will also be expanded and revised continuously.

Thematic Presuppositions

Albert Einstein placed his confidence, often against all available evidence, in a few fundamental guiding ideas or presuppositions, which he called "categories." These categories included simplicity, symmetry, causality, completeness, unity, unification and wholeness. These nontestable but highly motivating presuppositions are what Gerald Holton (1973, 1978 and 1986) refers to as "themata."

Einstein identified two components of our knowledge, the "rational" and the "empirical." These two components are "inseperable"; but they stand also in "eternal antithesis." He maintained that "propositions arrived at by purely logical means are completely empty as regards reality"… "through purely logical thinking we can attain no knowledge whatsoever of the empirical world"… scientific knowledge "starts from experience and ends with it." (Holton, 1986)

This two-dimensional dualistic view consists of two types of propositions: Propositions concerning empirical matters of fact, which can in principle be rendered in protocol sentences in ordinary language that command the general assent of a scientific community can be called *phenomenic propositions*. Propositions that are meaningful in so far as they are consistent within the system of accepted axioms can be called *analytic propositions*.

One may imagine them as lying on a set of orthogonal axes, representing the two dimensions of a plane within which the scientific discourse usually takes place. One may, however, define a third axis, rising perpendicularly out of it. This is the dimension orthogonal to and not resolvable into the phenomenic or analytic axes. It consists of categories that are not directly derivable either from observation or from analytic propositions, which is what Holton calls themata.

Einstein pointed out that the phenomenic-analytic dichotomy prevents the principles of a theory from being "deduced from experience" by "abstractions" – that is to say by logical means. "In the logical sense the fundamental concepts and postulates of physics are free inventions of the human mind." The elementary experience does not provide a logical bridge to the basic concepts and postulates of mechanics. Rather, "the axiomatic basis of theoretical physics… must be freely invented." (Holton, 1986)

For Einstein "the noblest aim of all theory" is "to make these irreducible elements as simple and as few as is possible, without having to renounce the adequate representation of any empirical content." In Einstein's (1919) essay "Induction and deduction in physics" he maintains that:

"… without any preconceived opinion, how should he (the researcher) be able at all to select out of those facts from the immense abundance of the most complex experience, and just those which are simple enough to permit lawful connections to become evident?"

It is possible to assemble a list of about ten chief presuppositions underlying Einstein's theory construction. Examples are symmetry;

simplicity; causality; completeness and exhaustiveness; continuum; and invariance. For Einstein it was not only a scientific need to view the world of separate phenomena as an expression of one great unity; it was also a psychological necessity. In one of his essays he says that: "… one wants to experience the universe as a single significant whole" (Holton, 1986).

Holton (1986) found that much the same can be said of most of the major scientists. Each has his own, sometimes idiosyncratic map of fundamental guiding notions. The scientist is generally not, and need not be, conscious of the themata he uses. Most of the themata are ancient and long lived and a small number of themata have sufficed us throughout the history of the physical sciences. Thematic analysis of the same sort has also begun to be brought to bear on significant cases in other fields.

If the principles are free inventions of the human mind, there should be an infinite set of possible axiom systems. How could there be any hope of success, except by chance? The answer is in the freedom to make such a leap, but not the freedom to make any leap whatever. The freedom is narrowly circumscribed by a scientist's particular set of themata that provide constraints shaping the style, direction, and rate of advance (Holton, 1986).

The most ancient and persisting of these thematic conceptions, acting as a motivating and organizing presupposition to this day, is the attempt since Thales – the "Ionian Fallacy" – to unify the whole scientific world picture under one set of laws that will account for the totality of experience accessible to the senses (Holton, 1986).

Sir Isaiah Berlin (1979), in his book *Concepts and Categories*, pointed out what he called the "Ionian Fallacy," the search, from Aristotle to Bertrand Russell and even today, for the ultimate constituents of the world in some nonempirical sense. The synthesis-seekers of physics, from Copernicus, who said that the chief point of his work was to perceive nothing less than "the structure of the universe and the true symmetry of its parts," to

Einstein's contemporaries, seem to imitate Thales in his view that one entity explains all (Holton, 1986).

Holton points out that the chief point in his view of science is that scientists, insofar as they are successful, are in practice rescued from the fallacy by the multiplicity of their themata, a multiplicity which gives them the flexibility that an authoritarian research program built on a single thema would lack. He refers rather to something like an Ionian Enchantment, the commitment to the theme of grand unification that inspired Einstein. In Einstein's papers we find evidence of this drive, which he later called "my need to generalize."

Themata are a necessary precondition in the creation of a new theory, but not a guarantee of success. Galileo succeeded where Thomas Harriot failed, Einstein succeeded where Poincaré failed, and Millikan succeeded where Felix Ehrenhaft failed (see Holton 1996). The scientist who succeeds experience a "sense of wonder," while those who fail experience a sense of frustration.

Constructing a Scientific Theory

In the previous sections of this chapter we looked at different aspects of the scientific process. In this section we will look at Einstein's model for constructing a scientific theory, as described in more detail by Holton (1986).

Einstein's preference for visual thinking is illustrated in the diagram of his model for constructing a scientific theory (Fig. 16, page 174, After Holton, 1986). The diagram indicates an essentially cyclical process.
The *E* (experiences) are given to us, indicated by the horizontal line, labeled "multiplicity [or variety] of immediate (sense) experiences." It represents the "totality of empirical fact" or "totality of sense experiences." In themselves the points on this plane of sense experiences

are bewildering. Einstein explained that "science is the attempt to make the chaotic diversity of our sense-experience correspond to a logically uniform [unified] system of thought." The chaotic diversity of "facts" is mastered by erecting a structure of thought on it that points to relations and order.

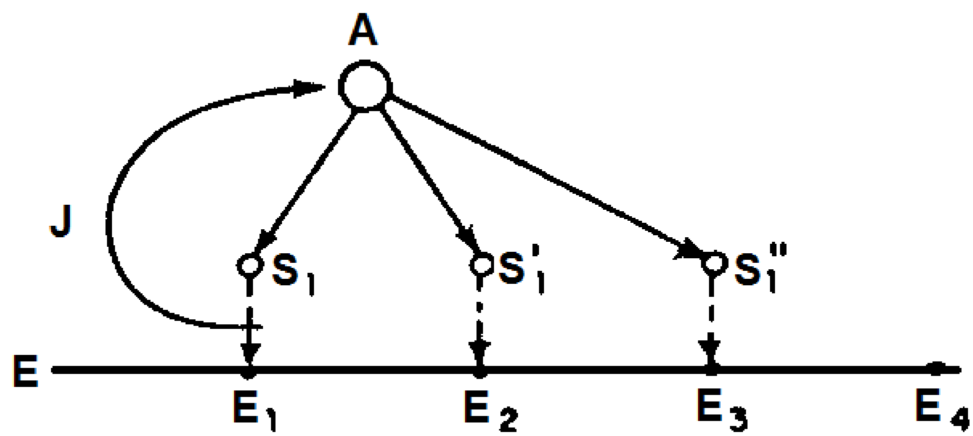


Fig. 16: Einstein's schematic model for constructing a theory (after Holton, 1986).

An arrow-tipped arch *J* to the top of the scheme symbolizes a bold speculative leap. At the top, high above the plane *E* is *A*, the "system of axioms" from which we draw consequences. Psychologically the *A* are based upon the *E*. There is, however, "no logical path from *E* to *A*, only an intuitive (psychological) connection, which is always 'subject to revocation.'"

The arc *J* represents the speculative leap to *A*, the axiom or fundamental principles which in the absence of a logical path have to be postulated on the basis of a conjecture, supposition, "inspiration," "guess," or "hunch." This involves the private process of theory construction or innovation, the phase not open to inspection by others and indeed perhaps little understood by the originator himself. The leap symbolizes precisely the precious moment of great energy, the response to the motivation of "wonder" and of the "passion of comprehension"… This leap is a "free creation of the human mind."

Einstein referred to David Hume's attack on induction, showing that "concepts which we must regard as essential, such as, for example, causal connection, cannot be gained from material given to us by the senses." There is no inductive method which could lead to the fundamental concept of physics. We can therefore have no certainty that our concepts have a necessary connection with the corresponding experiences and therefore theories are always precarious. Because all theories are "man-made" and the result of an extremely laborious process of adaptation, they are also hypothetical, never completely final, always subject to question and doubt. Einstein maintained that "there is no logical paths to these elementary laws; only intuition, supported by being sympathetically in touch with experience."

Just as there were in principle infinitely many points on the *E* level at the bottom of the schema, there are in principle infinitely many possible axioms or systems of axioms *A* at the top. The choice a given scientist makes out of all possibilities cannot be entirely arbitrary, since it would involve him in an infinitely long search.

From *A*, by a logical path, particular assertions are deduced – deductions which may lay claim to be true. Logical thinking is necessarily deductive, starting from the hypothetical concepts and axioms which were postulated, deriving the necessary consequences or predictions; if *A*, then *S, S', S''*… should follow.

In the final step the *S* are referred [or related] to the *E* (testing against experience). From the predictions (*S, S'*…) of the partly hypothesized, partly deduced scheme, corresponding observations need to be found on the plane of experience *E*. If these are found, the predictions have been borne out by observation, providing confidence in the previous steps – the jump from *E* to *A* and the deduction of *S* from *A*. The cycle has therefore been completed: from *E* to *A* to *S* to *E*.

However, even if the predictions are borne out, one cannot be too confident that the theory, the whole structure of conjecture, postulation, and deductions, is necessarily right. The first test is the criterion that "The theory must not contradict empirical fact." This is a principle of disconfirmation or falsification, and not an attempt to seek confirmation by empirical test.

Einstein's second criterion is what he called the criterion of "inner perfection." This included the "logical simplicity" of the premises… a judgement into which esthetic considerations and other preferences can enter prominently. Einstein warned to stay clear of theories that are patched up by ad hoc assumptions introduced just to make the deductions correspond better to the facts of experience as they continue to come in.

Since the leap from *E* to *A* at the beginning of the schema is logically discontinuous and represents the "free play" of the imagination, and since from such a leap can result an infinite number of *A* – virtually all of which will turn out to be useless for the construction of the theory system – how can one ever expect to be successful in this process except by chance? Something must guide the choice of the leap taken, if only because the premises must later pass the tests of simplicity.

Einstein recognized that "If the researcher went about his work without any preconceived opinion, how should he be able at all to select out of those facts from the immense abundance of the most complex experience, and just those which are simple enough to permit lawful connections to become evident?"

We can recognize the existence of, and at certain stages of scientific thinking, the necessity of postulating and using conceptions which are unverifiable, unfalsifiable, and yet not arbitrary, a class to which Gerald Holton has referred as *themata*. Different scientists may be attracted to different themata. Among the themata which guided Einstein in theory construction are: primacy of formal explanation; unity (or unification) and cosmological scale; logical parsimony and necessity; symmetry; simplicity;

causality; completeness; continuum; and constancy and invariance. A number of leaps may be possible from *E* to *A*, but only a few will survive the filtering action of the themata which a particular scientist has adopted.

In addition to surviving the filtering of themata, the postulates *A* should also survive the filtering process of whether their logical implications, the predictions *S* deduced from them, will correspond to observations in the plane *E*. In particular, a theory may supersede another if the postulates *A* can result in the deduction of *novel predictions*. If more than one theory competes with one another, two theory systems may separately come to a point of development where there is no essential difference in the number and types of phenomena (experimental evidences) which they can handle. But scientists may make their final choice based on a preferred system of themata.

Reasonable even if Impossible to Verify

To return to an earlier theme, we said that the process of induction involves assumptions that cannot be logically justified, and that hypotheses are formed by non-logical processes. Induction is based on the assumption that instances, of which we have had no experience, will resemble those of which we have had experience. Yet there can be no demonstrative arguments to prove that such an assumption must be valid. We can at least conceive a change in the course of nature, which sufficiently proves that such a change is not absolutely impossible. Our assumption that the future will resemble the past is not based on logical arguments: it is based entirely on habit. Induction from experience has no logical justification (Hume, 1739).

Even though the process by which hypotheses are created is not logical, hypotheses – once formed – are also generalized and assumed to be universally true. The "problem of induction" therefore also applies to hypothetico-deductive reasoning. Just as empirical generalizations that were true in the past need not necessarily be true in the future, hypotheses that were true in the past (although it can never be known that they were true even if they were true), need not necessarily be true in the future (Popper, 1963).

The implication of the "problem of induction" is that scientific theories cannot be verified. Scientific theories may well be true, but even if they are, we can never know that they are true (Popper, 1963). Even factual propositions cannot be proven from experience (Popper, 1959). If factual propositions cannot be proven then they are fallible. And if they are fallible the clashes between theories and factual propositions are not "falsifications," but mere inconsistencies. So theories cannot be conclusively falsified either. Furthermore, a theory can always be protected from falsification by modifying some auxiliary hypotheses. Scientific theories are not only equally unprovable and equally improbable, but they are also equally unfalsifiable. Generally speaking, theories and hypotheses cannot be appraised in isolation; rather, a continuous series of theories should be seen within the context of an ongoing research programme (Lakatos, 1978a).

It is reasonable to act on the assumption that the future will, in many ways, be like the past, and that well-tested theories will continue to hold, since we have no better assumption to act upon. It is also reasonable to believe, however, that the future will be very different from the past in many important ways, and that such a course of action will at times result in failure (Popper, 1963).

The Absence of the Scientific-Philosophic Tradition

Gerald Holton (1986) identifies an important paradox in contemporary science. Some of the pioneering scientists in history engaged in philosophical debates about the nature of science itself. Examples include debates between Newton and Leibnitz, or more recently between Planck and Mach, or amongst Heisenberg, Bohr, Born, Scrödinger, Einstein, and de Broglie. Einstein maintained that: “Epistomology without contact with science becomes an empty scheme. Science without epistemology is – in so far as it is thinkable at all – primitive and muddled.”

This classical preparation in philosophy of science now seems to be dead. Working scientists today seem to disregard the more recent and current works in the philosophy of science. However, despite the decay of the scientific-philosophic tradition, science today is without doubt as powerful and interesting as it has ever been. This raises the question: How can science be done so well without the conscious contact with epistemology that characterized the classical mode?

Holton further points out that during periods of rapid advance in science concern for philosophy of science seem to be temporarily suspended. Sooner or later science has always run up against some severe, apparently insurmountable conceptual obstacles. During these periods of despair some of the best scientists will turn again to philosophy. But for the time being such philosophical preoccupations are in a state of hibernation. The scientist does not need, and in fact does not use, a philosophy of science, whether or not it is held consciously and openly.

I would argue that the reason why scientists can be successful in the absence of the scientific-philosophic tradition is because scientific reasoning is an innate ability of the human mind. For the same reason that hunter-gathers have been successful in applying scientific reasoning in the absence of a conscious philosophical tradition, most contemporary scientists are successful simply applying their innate scientific reasoning.
As Holton points out, it is only during times of crises, when science is confronted with insurmountable conceptual obstacles, that scientists need to engage in scientific-philosophical debates.

Why Science is so Successful

One of the mysteries of science is why it is so successful. Why, for example, should a mathematical equation that applies to one context be applicable in widely different contexts. Science is motivated by a constant search for unities and simplicities behind nature's spectacle of variety, reaching for ever higher, more general conceptions that allow one to see common features among the phenomena. Albert Einstein confessed that, concerning "the high degree of order in the objective world," that "one has no justification to expect it *a priori*. Here lies the sense of 'wonder' which increases ever more with the development of knowledge" (Holton, 1986).

From an evolutionary point of view, the origin of the creative scientific imagination due to natural selection *by* nature may explain why science is so successful *in* nature.

If the art of tracking is indeed the origin of science, it would explain how the human mind evolved the innate ability to do science. It is easy to see how natural selection for tracking would have resulted in the success of tracking in nature. But this still leaves the mystery of how, if natural selection resulted in the evolution of tracking, can science be so successful in physics at the levels of atoms through to cosmology. This paradox can only be resolved if it is assumed that a reductionist approach to explaining reality reflects an underlying truth about reality.

Tracks and signs can be quite bewildering in their variability and complexity. To make sense of animal tracks the human mind evolved the ability to create simplified models that make it possible to recognize patterns and make predictions. Only by creating hypotheses about the underlying regularities and structural simplicity is it possible to make sense of tracks and signs (see *Underlying Simplicity, Symmetry and Unity*, page 90, Chapter 5). These hypotheses explain the morphology of animals' feet as well as patterns in animal behavior within an ecological context.

The same underlying order that is evident in animal morphology and animal behaviour may reflect a fundamental underlying order in all aspects of reality. This underlying order may be defined by qualities like causality, simplicity, symmetry, internal consistency and unity. The order that is evident in animal morphology and animal behaviour may be determined by an underlying order in the animal's DNA, which may be determined by an underlying order in atoms, which may be determined by an underlying order in sub-atomic particles. Just as fractal geometry may repeat the same pattern at different resolutions (Mandelbrot, 1982), the same structural order may repeat itself at different resolutions in nature. There may well be aspects of reality that have holistic, emergent qualities that cannot be reduced, but at its core reality must have an underlying structure that can be "grasped" by means of reductionism. Through natural selection for tracking animals, the human mind may have evolved an innate ability to "grasp" the underlying structure of nature.

Superstition and Irrational Beliefs

Even if scientific reasoning is innate, it is not to say that everyone can be a great scientist. All humans have the innate ability to develop language, but not all people become great novelists or poets. Similarly, not all people are potential Einstein's.

However, if scientific reasoning is innate, it leads us to another paradox in human evolution: why are superstition and irrational beliefs so common?

In hunter-gatherer bands individuals may vary from very superstitious through to rational and skeptical (see *Skepticism and Individualistic Theories and Hypotheses*, Chapter 5). For hunter-gatherers to survive it was not essential that everyone had a rational, scientific approach. A small percentage of hunters produced most of the meat (see *Mental Qualities*, Chapter 5) – as long as some hunter-gathers were rational and scientific, the band would survive. It did not matter if some of the others had superstitious or irrational beliefs.

Superstition may well have its origin in the creative scientific imagination. Hypothetico-deductive reasoning involves the creation of a hypothesis to explain observations, which makes it possible to make novel predictions that can be tested by observation. A hypothesis is a creation of the human imagination. It could be argued that a superstitious belief is simply a "creative hypothesis," an "explanation" created by the human imagination, which cannot make novel predictions and therefore cannot be tested by observation. Superstition may simply be creative "hypotheses" without the deductive predictions that can be tested. Once humans evolved the creative ability to engage in scientific hypothetico-deductive reasoning, they also had the ability to create superstitious beliefs that could not be tested. Superstition may therefore be an inadvertent nonadaptive by-product of creative science.

Even if scientific reasoning is innate to the human mind, superstition may not only be an inevitable consequence of creative thinking, it may well be increasing as we become more urbanized and alienated from nature. While some hunter-gatherers were superstitious, the successful scientific hypotheses were "selected for" by the success or failure of hunters. Today we no longer depend on hunting and gathering for our survival and our hypotheses are therefore not subjected to a form of "natural selection." To ensure reliable science we therefore need an artificial selection process, involving data collection protocols, scientific methods and critical peer review.

Due to genetic variability in the human population, there will always be people who are superstitious and irrational. Mostly this may be perfectly harmless, since many people who have some irrational beliefs may also believe that we need science and technology. At the very least, most people who do not understand science appreciate that you need physics and mathematics to develop smart phones – and smart phones seem to be useful things. And even someone who believes in irrational superstitions can still make a contribution to science in the form of very basic but accurate bird observations.

In a hunter-gatherer context, even if only twenty to thirty percent of hunters had a rational, scientific approach, they would have provided enough meat for the whole band to survive. It therefore did not matter if most band members held superstitious or irrational beliefs. However, in modern democracies, the majority of voters determine the political leadership. Political leaders who hold irrational and superstitious beliefs, and may even be anti-science, clearly may have serious negative implications for human welfare.

9

Science, Language and Art

The evolution of science would have required the evolution of language and art. Complex scientific ideas would have required complex language. Storytelling and artistic expression would have been instrumental in transmitting scientific knowledge. Archaeological evidence for art may therefore provide indirect evidence for the origin of science.

The Art of Storytelling

Storytelling is critical to prepare yourself for life-threatening situations. You cannot learn from experience how to react to a lion charging you, because you may not have a second chance if you get it wrong. Clearly, at some point in the past, numerous hunter-gathers may have lost their lives before someone discovered that you can call a lion's bluff. But once this was discovered, this knowledge would have been passed on culturally.

Kalahari trackers taught me how to deal with a charging lion, acting out the process in a very dramatic way. You need to hold your ground and look the lion in the eyes, shouting and throwing sticks and stones at it. Never turn your back on a lion and never run away from it. More than ten years later I was charged by a lioness with cubs. To prepare yourself for such an eventuality you need to act out in your imagination what to do. You visualize a lion charging you and mentally rehearse the appropriate reaction, and do this repeatedly until it becomes second nature. When it happens, you do not have time to think about it. You need to react instantaneously and intuitively do the right thing. To complicate matters, different species (leopard, rhino, buffalo or elephant) require different reactions, and for each species it would depend on the context (whether or not you are inside its "comfort zone" or whether it has young). You also need to read its "body language" (for example, its posture, whether it flattens its ears and sweeps its tail from side to side) to know whether it is a mock charge (bluffing) or a serious charge (see Liebenberg, et al 2010). This example illustrates the adaptive value of dramatized storytelling and repeatedly acting out various potential confrontations in your imagination.

Hunter-gatherers share their knowledge and experience with each other in storytelling around the campfire. Although this seems to involve relatively little direct transmission of information or formal teaching, much knowledge is gained *indirectly* in a relaxed social context. Hunter-gatherers take great delight in lengthy, detailed and very gripping narrations of events they have experienced, with non-verbal expression used to dramatize their stories. Artistic expression is involved in relating events in an entertaining way, thereby ensuring a continuous flow of information. Storytelling in this way acts as a medium for the shared group knowledge of a band (Blurton Jones and Konner, 1976; Biesele, 1983).

The art of storytelling is enjoyed by all individuals irrespective of whether potentially useful information may or may not be of use to anyone subsequently. For some individuals a particular story may be enjoyed even if the information transmitted is of no use to them – they enjoy art even if it is useless to them. For other individuals a story may coincidentally have potential usefulness, since some of the information transmitted may be useful at a later stage when the listeners find themselves in circumstances similar to that experienced by the storyteller. Storytelling therefore owes its effectiveness as a medium for the shared group knowledge to the fact that it provides aesthetic pleasure irrespective of whether or not the information transmitted may be useful.

Knowledge for the Sake of Knowledge

Hunter-gatherers developed knowledge for the sake of knowledge (see Chapter 5) that may have had unforeseen survival value in a hunter-gatherer context. In a hunter-gatherer context the unforeseen benefits of knowledge may happen within the lifetime of an individual, so could therefore be easily explained by means of natural selection. The unforeseen benefits would affect the survival of the hunter in a direct way, thereby increasing the survival of the band and the population as a whole.

One of the paradoxes of knowledge for the sake of knowledge is that scientific theories developed over centuries with no conceivable practical value may have unforeseen survival value. The same principle that increased the survival of hunter-gathers may also increase the chances of survival of humans over many generations. Perhaps one of the most intriguing examples is the heliocentric model of the solar system created by Aristarchus of Samos (310 BC – 230 BC). This hypothesis was revived by Copernicus 1800 years later. Today, understanding how changes in the Earth's tilt and orbit around the sun affected the glacial to interglacial climate changes in the past is crucial in understanding the potential severity of human-made climate forcing and the risk of initiating runaway greenhouse warming (Hanson, 2009). Even the hypothesis of Aristarchus, with the refinements developed over two thousand years, may be subjected to the ultimate test of natural selection in the sense that the survival of humans may depend on it.

The ultimate test of science is not only whether theories may be true or not, but whether humans have the capacity to act on the belief that they may be true. Even if scientific theories are true, and we may not be able to prove that they are true, a failure to act may result in the extinction of humans. Natural selection does not give us a guarantee that successful scientific theories will survive, only that human populations who act on the basis of successful theories may survive. Conversely, human populations who believe in theories, or myths, that are not true, may not survive.

We may enjoy scientific knowledge for aesthetic reasons, as knowledge for the sake of knowledge. Individual scientists may derive great personal satisfaction and meaning in creating scientific theories. What motivates scientists is perhaps best described by Einstein (1954) as "the state of feeling which makes one capable of such achievements is akin to that of the religious worshipper, or of one who is in love… one's daily strivings arise from no deliberate decision or program, but out of immediate necessity."

The adaptive value of science derives from the fact that scientists enjoy doing science irrespective of whether or not it has any practical applications. But this in itself may be as a result of natural selection in the first place. Developing science for its own sake results in exploring the complexities of nature beyond the immediate necessities, which may have unforeseen benefits in the future. Ultimately, the adaptive value of science is the way these unforeseen benefits may improve human welfare and our chances of survival.

Conversely, science may also have unintended negative impacts. In a hunter-gatherer context, non-adaptive side-effects of wrong or bad theories, such as superstitious beliefs, may have been relatively harmless. But in a modern context, where science has a much larger impact on society, unintended negative impacts, or even intentional negative impacts (such as military research), may have severe consequences for human welfare.

Art for Art's Sake

Prehistoric art has been variously interpreted as a medium of hunting magic, or as part of sacred rituals or initiation ceremonies. Paintings have also been interpreted as symbolizing male and female images, reflecting a fundamental division in the world, or as representing social relations within bands and between them. Since there are many possibilities, the true symbolic meaning of prehistoric art, if any, may never be known. Denis Dutton (2009) gives a compelling argument that it is time to look at the arts in the light of Darwin's theory – to talk about instinct and art.

Some scholars have dismissed the notion that hunter-gatherer rock art was *l'art pour l'art* – "art for art's sake" (see, for example, Lewis-Williams and Challis, 2011). I would argue, however, that "art for art's sake" provides the most powerful explanation of the evolutionary origins of art. My argument does not deny the complexity and richness of prehistoric rock art. On the contrary, I would argue that the complexity of rock art is due to "art for art's sake" in the same way that the complexity of creative science is due to "knowledge for knowledge sake."

If we consider the very nature of creativity, it is unlikely that a single explanation can account for all the reasons why art was practiced. Rather, art was probably used in many ways and developed for a multitude of reasons. The adaptive value of art may well reside in the fact that the aesthetic pleasure derived from it is not merely a function of the transmission of useful information. The usefulness of art, from an evolutionary point of view, may well be, as Oscar Wilde (1891) maintained, that "all art is quite useless." The aesthetic pleasure has a quality which makes people enjoy it repeatedly. Information is therefore not related in a manner that would be dull and boring. The adaptive value of art is illustrated by the role storytelling plays in hunter-gatherer subsistence.

Metaphor and the Origin of Language

The transition from track and sign recognition (involving inductive-deductive reasoning in systematic tracking) to track and sign interpretation (involving hypothetico-deductive reasoning in speculative tracking) may well have involved the evolution of the intellectual ability to create metaphors and develop complex language. Metaphors are more than just direct associations - they involve the understanding of an underlying meaning that has similarities but also contain something more, in the same way that a hypothesis contains more than the direct associations of tracks and signs.

The use of metaphor in science shows that metaphor is a way of adapting language to reality and that it can capture genuine laws of the world, not just project images onto it. The fact that science can make novel predictions about reality implies that some metaphors can express truths about the world, that metaphors can objectively capture aspects of reality (Pinker, 2007).

Scientists constantly discover new entities that lack an English name, so they often adopt a metaphor to supply the needed label. As scientists come to understand the phenomenon in greater depth, they highlight the aspects of the metaphor that should be taken seriously while the aspects that should be ignored fall away. The metaphor evolves into a technical term for an abstract concept. Scientists do not "carefully define their terms" before beginning an investigation. Rather they use words loosely to point to a new phenomenon in the world, and the meanings of the words gradually become more precise as the scientists come to understand the phenomenon better (Pinker, 2007).

It is interesting to note that metaphors based on the human body are undoubtedly the most numerous in the sciences. To understand the body as metaphor, and as a source of metaphors derivable directly or by transformation rules from it, we must remember that our own experience of our bodies is prescientific (Holton, 1986). The preponderance of metaphors in science based on the human body may well be due to an innate tendency to engage in anthropomorphic projection, which may have its origins in tracking.

The recognition of natural signs in systematic tracking may have preceded the creation of metaphors and the development of complex language (since it involves less advanced reasoning). However, once humans evolved the ability to interpret signs in speculative tracking (using hypothetico-deductive reasoning), they would also have had the ability to create metaphors. Natural selection for speculative tracking may well have played a role in the evolution of language. And the ability to develop a complex language would have been essential in developing the scientific knowledge required for speculative tracking.

The creation of hypotheses goes hand-in-hand with the creation of metaphors. When you conceive a hypothesis in your mind, you need to create a suitable metaphor to communicate and explain it to someone else. The ability to create metaphors would therefore have been essential once humans developed the ability to create hypotheses, at least to the extent that they needed to communicate their new ideas to others.

Without metaphors, trackers would have had to keep their original ideas to themselves, unable to communicate them to others. Each individual tracker would have had to develop his or her hypotheses in isolation. Each hunter would have had to discover the hidden, unseen world of animal behaviour by themselves. There may well have been a period of transition from systematic tracking to an individual form of speculative tracking (without sharing ideas with others) to a more advanced collective speculative tracking, where hunters were able to share ideas using metaphors and a complex language.

During the individual form of speculative tracking, individual trackers may have been able to visualize and form an internal representation of animal behaviour that would explain tracks and signs, but they may have been unable to communicate these visual images to others with words. It is also possible that they may have used other forms of communication. For example, trackers may have mimicked the activity visualized, or use their hands to gesture movements and activities. The first primitive "metaphors" may have involved combining a word associated with a known activity with mimic and/or hand gestures to illustrate how the visualized activity is *different* from what the word represents. In this way they may have communicated that the new activity is *like* a known activity associated with a word, but it is *different* in a way suggested by a gesture. Over time, a hand gesture may have been replaced by a different voice tonality to suggest that a different meaning is intended, resulting in the development of metaphors. In the /Gwi and !Xõ languages, for example, the same word can have different meanings depending on the voice tonality.

Evidence of Tracking in Prehistoric Art

Indications of an anthropomorphic way of thinking are found in Upper Palaeolithic art. Some figures, for example, appear to be half-human, half-animal. Although these figures may simply depict hunters wearing animal disguises, it is conceivable that the artist may have attached some symbolic significance to it. Perhaps such depictions symbolize the way trackers identify themselves with their quarry.

The earliest direct evidence of tracking is in the form of animal footprints depicted in prehistoric cave art. One useful example is an early Magdalenian painting in the cave of El Castillo, north-west Spain, depicting bell-shaped figures in reddish-brown paint (see Fig. 17, page 192, after Marshack, 1972; Prideaux, 1973). These figures (which have been interpreted by Andre Leroi-Gourhan as stylized female sex organs), closely resemble ungulate hoofprints in soft substrate (see Fig. 18A, page 193). The points at the back of the footprints reproduce the impression created by the dew claws when the animal's feet sink into soft mud or snow. The forefeet are usually larger than the hind feet, and in soft substrate the forefeet appear also more splayed than the hind. The lines down the middle of the middle and lower right footprints may indicate that they are more splayed than the other two. If this is so, the middle footprint would represent that of the left forefoot, and the lower right footprint that of the right forefoot. The extreme left footprint would then represent that of the left hind foot, and the uppermost footprint that of the right hind foot. Taken as a whole this track group closely resembles that of a jumping animal (see Fig. 18B, page 193, after Bang and Dahlstrom, 1972). The footfall sequence is first the right fore followed by the left fore, and then the left hind followed by the right hind. For large, heavy animals jumping is a very exhausting method of locomotion and almost only used in very soft substrate, such as soft mud or deep snow, or to clear obstacles (Bang and Dahlstrom, 1972). The reddish-brown colour of the figures suggests that they may represent footprints in soft mud or wet sand, rather than snow.

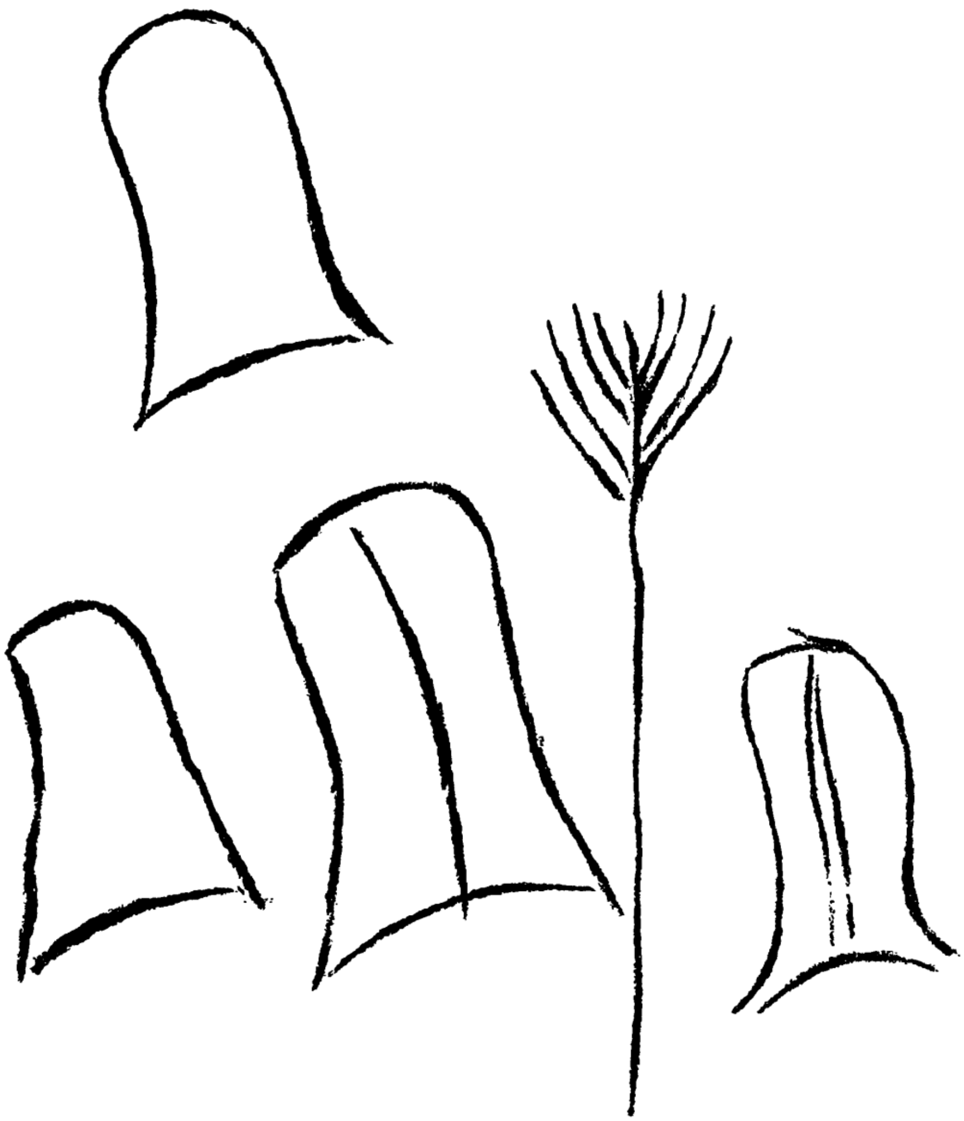


Fig. 17: Cave painting depicting hoof tracks (after Marshack, 1972; Prideaux, 1973)

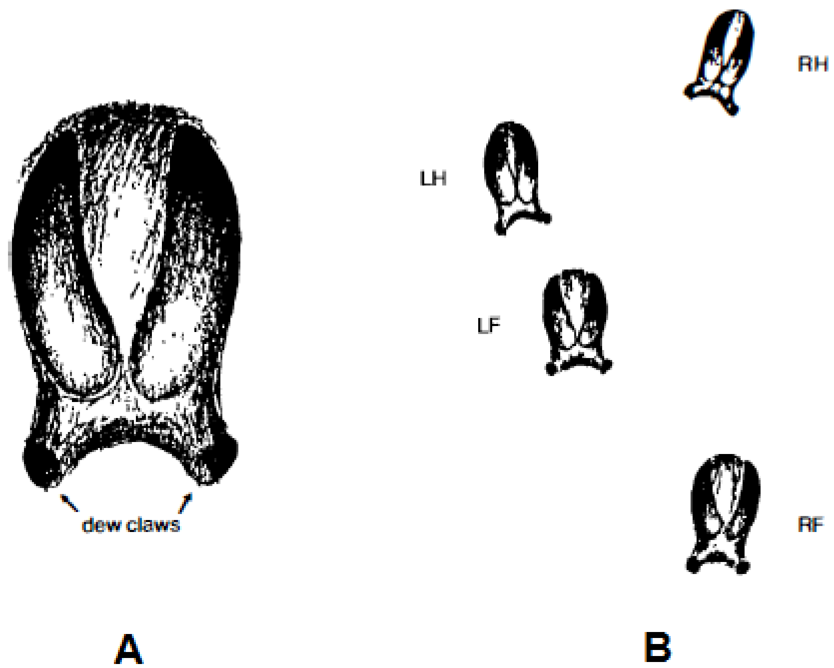


Fig. 18: (A) Hoofprint in soft substrate (B) Jumping gait

What is remarkable about this painting is the artist's attention to detail and his/her ability to create a meaningful interpretation of spoor. If the figures do represent footprints in soft mud rather than snow, it suggests that the artist-hunter did not merely practice simple tracking but was capable at least of systematic tracking, and possibly speculative tracking. The jumping gait in soft substrate may have a special significance: hunters may perhaps have driven animals into soft mud to exhaust them. That the hunter was an artist also indicates that he/she possessed a creative imagination and may therefore have had the intellectual abilities to be a modern speculative tracker.

Empathy in Science and Art

Not only may art have played some role in transmitting scientific information in hunter-gatherer societies, there also seem to be a correspondence between the intellectual processes involved in science and in art.

The aesthetic appreciation in art combines an element of empathy. When one contemplates a work of art, one projects oneself into the form of the work of art, and one's feelings are determined by what is found there (Read, 1968). In the process one may in a sense identify with the artist (Fry, 1920). Empathy in art, I would argue, corresponds to the element of anthropomorphism in science (see Chapter 8) and in particular in the art of tracking.

Science involves making observations or experiments designed to find out whether the imagined world of our hypotheses corresponds to the real one. A speculative act of imagination underlies every improvement of natural knowledge. It was not a scientist or a philosopher but a poet who first classified this act of mind. The poet Shelley used the word *poiesis*, standing for making, fabrication or the act of creation. In his *Defense of Poetry* (1821), Shelley declared that "poetry comprehends all science," thereby classifying scientific creativity with the form of creativity more usually associated with imaginative literature and the fine arts (Medawar, 1984).

If this correspondence indicates a fundamental similarity in the creative processes in both science and art, then archaeological records of art and symbolism may provide indirect evidence of the potential creative scientific abilities of prehistoric humans.

10

Modern Tracking

Over the last ten thousand years, virtually every aspect of human culture has changed. The food we eat, the homes and shelters we live in, the clothes we wear, our language, music, stories, science, technology, social organization have all changed in fundamental ways that make modern cultures unrecognizably different from hunter-gatherer cultures. One aspect of human culture has remained unchanged over the last ten thousand years – all humans have retained a basic ability to recognize and interpret footprints on a beach.

When you look at footprints on a beach, what you see and the way you interpret them is essentially exactly what a hunter-gatherer would have seen and interpreted a hundred thousand years ago. We still use the same reasoning to understand what we are looking at. The hunter-gatherer may have been a more sophisticated tracker, but looking at human footprints on a beach may be one of the few aspects, perhaps the only aspect, of human culture that links us with hunter-gatherer cultures more than a hundred thousand years ago.

The Last Hunters

Even hunter-gatherer cultures, such as those in the Kalahari, have changed over the last 50 years. Extensive fencing began in Botswana in the 1950s, devastating wildlife in the central Kalahari and making it increasingly difficult to hunt (Silberbauer, 1965; Child, 1972; Owens and Owens, 1985). Hunter-gatherers in the Kalahari have moved away from a significant dependence on hunting since the 1960s (Marshall Thomas, 2006). Today, hunters mainly use dogs and some hunt with horses, which are much more efficient than hunting with bow-and-arrow or persistence hunting (Liebenberg, 2006). Once dogs and horses are introduced into an area, other hunting methods become less competitive. The recent observations of persistence hunting and bow-and-arrow hunting may well represent the tail-end of a dying tradition.

Recent hunter-gatherers often hold on to "traditional" crafts, music and dancing largely for tourism as a means to earn a living in a modern socio-economic context. In many cases "traditional" crafts have become more elaborately ornate in response to commercial demands, which in itself is a perfectly natural form of culture change in response to changed socio-economic demands. Bows-and-arrows are now made to sell to tourists rather than for hunting (they are often too small and too crudely made to be effective as weapons). One hunter told me that he has not hunted with bow-and-arrow for many years, because every time he makes a bow-and-arrow set, the commercial crafts dealers buy it from him. He sells it because he is hungry, and because he can still hunt in other ways, like running down and animal. Ironically, the commercial trade in traditional bow-and-arrow sets, often promoted as a way to keep the tradition alive, may well have contributed to the decline in traditional bow-and-arrow hunting.

The one aspect of hunter-gatherer culture that can be applied in a modern context is the art of tracking. It is also the one aspect of hunter-gatherer culture that all modern humans can identify with. Not only can traditional trackers benefit by working as trackers in a modern economy. By sharing their tracking expertise, people from other modern cultures can benefit by learning more about the roots of science.

The cover of this book shows Karoha Langwane, a /Gwi tracker from Lone Tree in the central Kalahari, Botswana. You can watch Karoha conducting the persistence hunt in Episode 10 of the BBC documentary *The Life of Mammals,* presented by David Attenborough. A video link can be found on www.cybertracker.org to the BBC Earth video of the persistence hunt (http://cybertracker.org/persistence-hunting-attenborough). As far as we know, Karoha may well be one of the last traditional hunters who practiced the persistence hunt.

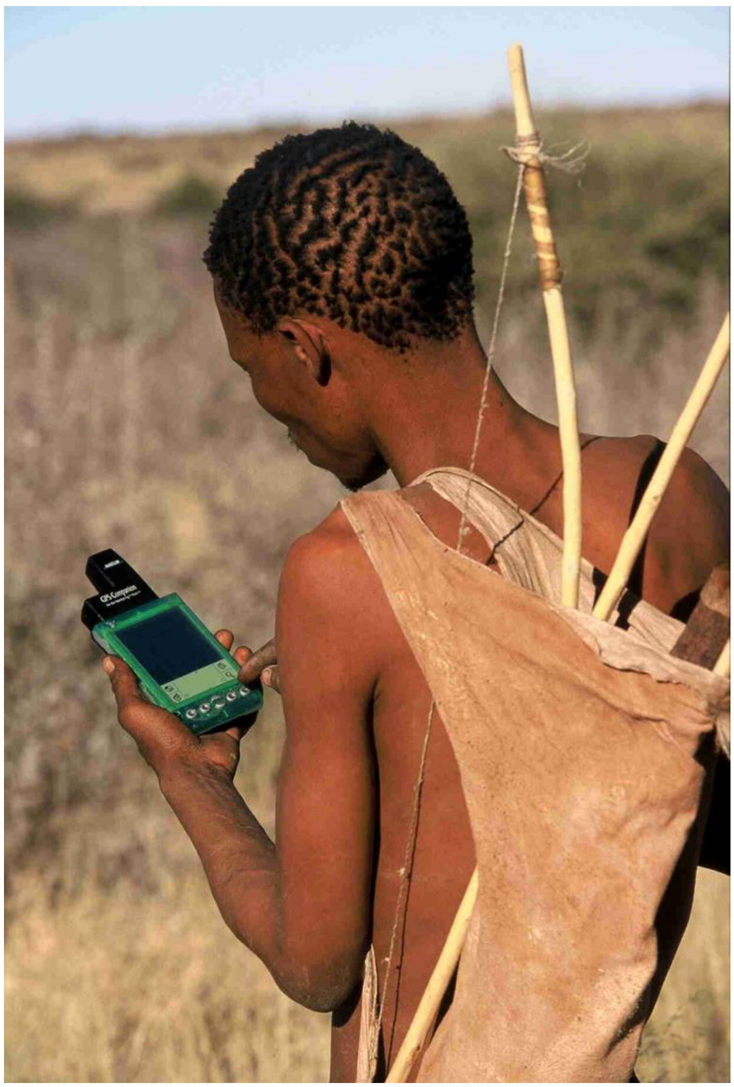


Fig. 19: Karoha using the CyberTracker (Photo Rolex/Eric Vandeville)

Karoha is also one of the most proficient users of the CyberTracker field computer (Fig. 19). He can use the CyberTracker to capture data, download the data onto a pc, view the data on a map, make a back-up of the data onto an external hard drive, recharge the batteries, and organize the computer equipment for the field. He was employed to train other /Gwi and !Xõ trackers for the Western Kalahari Conservation Corridor project, which involved detailed animal track surveys of wildlife. Karoha has inspired younger men, who are no longer hunting with bow-and-arrow, to become trackers.

You can watch Karoha using the CyberTracker in the video "Tracking in the Cyber Age" on www.cybertracker.org:

http://cybertracker.org/tracking-in-the-cyber-age

Karoha represents a profound cultural leap from being one of the last persistence hunters, a tradition that may well go back two million years, to using his traditional knowledge with cutting-edge computer technology to make a contribution to modern science and conservation management. His story gives us hope for the future. If he can do this out there in the middle of the Kalahari, where he lives in a village surrounded by extreme poverty, then anyone, no matter where they find themselves, can get involved in science.

The implications for community participation in science are far-reaching. Imagine communities throughout the world gathering data… from remote villages in the Kalahari, the Congo, Australia and Mongolia,… to school children in New York's Central Park, to London, Paris, Tokyo, New Delhi and Beijing… citizens gathering data on birds, animals, plants… millions of people all over the world sharing their data on the Internet (the Cloud), creating a worldwide network to monitor the global ecosystem in real time.

Trackers in Scientific Research

The scientific merits of traditional tracking are not just of academic interest, because they have practical implications for the employment of modern trackers in scientific research. To interpret animal tracks, the tracker must have a sophisticated understanding of animal behaviour. There is, in principle, no limit to the level of sophistication to which a tracker can develop his or her expertise. Apart from knowledge based on direct observations of animals, trackers gain a detailed understanding of animal behaviour through the interpretation of tracks and signs. In this way much information can be obtained that would otherwise remain unknown, especially on the behaviour of rare or nocturnal animals that are not often seen.

Expert trackers can give valuable assistance to researchers studying animal behaviour. Combining traditional tracking with modern technology, such as radio tracking and camera traps, may enable the researcher to accomplish much more than by applying either method on its own. Trackers can also extend the capacity of researchers to gather data by orders of magnitude. As long as the scientist is satisfied that the data collected by trackers are reliable, a team of trackers who go out on daily patrols can gather large quantities of very detailed data on an ongoing basis.

In the past trackers have been used in research on animal behaviour, but received little or no recognition for their contributions. Recently some researchers have recognised the contributions of trackers by including them as co-authors of papers. Involving trackers in scientific research has already resulted in startling new discoveries that would not have been made without them. Trackers who cannot read or write have been cited as co-authors of papers published in scientific journals (See Berger et al., 1993; Berger et al., 1994; Liebenberg et al., 1998; Liebenberg et al., 1999; Stander et al., 1997a; Stander et al., 1997b; Elbroch et al. 2011). In particular, Stander et al (1997) quantifies the accuracy and reliability of trackers in scientific research. In order to test the trackers, Stander spent time at a water hole, recording the activities of animals. The following day he took the trackers to the water hole and tested their ability to interpret the tracks. The Ju/'Hoan San team was correct in most (98% of 569) spoor reconstructions. Most significant of these were the correct identification of individually known animals and the reconstruction of complex behaviour from spoor.

Today the knowledge of trackers employed in national parks are not subjected to the same 'natural selection' as hunter-gatherers, since they no longer depend on tracking skills for their survival. Objective evaluations are therefore required to distinguish good trackers from poor trackers. Formal qualifications help to validate the accuracy of trackers, which in turn means that data collected by trackers would be accurate.

Tracker Evaluations and Observer Reliability

Over the last twenty years traditional tracking skills in southern Africa have been lost at an alarming rate. The previous generation of traditional trackers has grown old without ever receiving any recognition for what they can do. Over the last fifteen years some of the best trackers have passed away, their knowledge and skills irretrievably lost. Meanwhile, the younger generation had no incentive to become expert trackers. Among hunter-gathers in the Kalahari, the bow-and-arrow and persistence hunting have been abandoned as the use of dogs and horses were introduced. This has resulted in a decline in tracking skills, since the dogs are used to do the tracking.

To revitalize the art of tracking it should be recognised as a specialised profession. Trackers can play an important role in research, monitoring, ecotourism, anti-poaching and crime prevention in nature reserves and national parks. Creating employment opportunities for trackers provides economic benefits to local communities. The employment of trackers will also help to retain traditional skills that may otherwise be lost in the near future.

In order to develop the art of tracking as a modern profession, very high standards need to be maintained. In national parks and in the eco-tourism industry there has been an increasing need to verify the abilities of rangers and trackers. Rangers are used to gather data for monitoring wildlife and it is important to validate that the data they gather is accurate. Tracker certificates help to validate the reliability of trackers by providing an objective test of observer reliability. Trackers are graded in order to determine their level of expertise, so that they can be promoted according to different salary scales. Seven levels are recognized, from Tracker I to Professional Tracker, Senior Tracker, Evaluator and Master Tracker (see www.cybertracker.org). This provides an incentive for trackers to develop their skills.

The CyberTracker tracker evaluation covers the fundamental principles of tracking as well as the finer details and sophisticated aspects of tracking. This is done on an individual basis, depending on the level of each candidate. The evaluation is in the form of a practical field test. The tracker evaluation involves an accredited CyberTracker Evaluator who selects a number of tracks and signs in the field. Each candidate is then tested individually on each track and sign. Rather than pointing out details, each individual is first asked to give his or her own interpretation. Mistakes are corrected and explained continuously throughout the duration of the evaluation. This process identifies the strengths and weaknesses of each candidate in order to develop the potential of each individual in accordance to his or her level of skill.

The apprentice tracker is given a percentage obtained for the evaluation. The progress a tracker makes will depend to a large extent on his or her incentive to practice on an ongoing basis. Someone who is not able to develop his or her own skills will never become an expert tracker. The evaluation is therefore intended to teach trackers how to develop their own skills. The CyberTracker tracker evaluation system has also proved to be a very efficient training tool (Wharton, 2006).

Wildlife research often relies upon skilled observers to collect accurate field data (Wilson and Delahay, 2001). However, when the skill level of the observers is unknown, the accuracy of collected data is questionable (Anderson, 2001). Observer reliability is an important issue to address in wildlife research, yet it has often been overlooked or assumed to be high (Anderson, 2003). Measuring observer field skills enables managers to select the most qualified observers, thereby increasing confidence in collecting data (Evans, et al, 2009).

Survey methods involving identification of animal tracks are especially susceptible to observer errors (Wilson and Delahay, 2001). Although tracks and signs (including scat, hair, burrows and other indicators) can be the most efficient way to detect elusive animals (Beier and Cunningham, 1996), several factors (such as substrate quality, moisture level, age of track, animal movement) can cause tracks to be highly variable and difficult to identify. In surveys using tracks and sign, confidence in observer skills is of fundamental importance to the reliability of collecting data.

The standardized CyberTracker Tracker Evaluation procedure was used to assess the accuracy of observer reliability in counts of river otter tracks conducted by the Texas Parks and Wildlife Department. It was found that experienced observers misidentified 37% of otter tracks. In addition, 26% of tracks from species determined to be “otter-like” were misidentified as otter tracks (Evans et al, 2009). The educational utility of the CyberTracker Tracker Evaluation system was also demonstrated, showing substantial improvement in the scores of participants who attended the first evaluation (with an average score of 61%) and a second evaluation three months later (with an average score of 79%). This study demonstrated the necessity to reduce observer error in indirect sign surveys by adequately training and evaluating all field observers (Evans et al, 2009).

Many wildlife studies would benefit greatly from adopting standardized methods of evaluating skills of field biologists and data collectors. Methods such as the track and sign evaluation used in the study could be applied to a variety of research fields, both for testing validity of preexisting data and for quantitatively evaluating skills of field observers (Evans et al, 2009).

The CyberTracker tracker evaluation system has also demonstrated how the expertise of African trackers can be transferred to trackers in the developed world, such as the USA. The evaluation system was first developed in southern Africa to assess the skills of African trackers. Over a period of three years the American tracker and author Mark Elbroch mastered the CyberTracker evaluation system. In the process he improved his own tracking skills while being assessed in South Africa according to the standards set for African trackers, earning the Senior Tracker certificate. This then enabled him to initiate the CyberTracker evaluation system in the USA, applying the same standards to American trackers.

From its origins in the Kalahari, CyberTracker has now found its way into conservation projects worldwide. Most users simply use the CyberTracker software to record data. But the art of tracking also represents the most sophisticated and refined form of human observation. A fleeting glimpse of a small bird disappearing into a thick bush is closer to a *sign* of a bird than a clear sighting. A distant sighting of a whale in rough seas can be just as difficult to identify as an indistinct track. A dried out twig, with no flowers or green leaves, can make identification of a plant as difficult as identifying the faintest sign in the sand.

Whether looking at birds, butterflies, plants, whales, tracks or signs, human observations can be infinitely complex. The master trackers of the Kalahari can inspire the development of increasingly refined observation skills.

The CyberTracker Software Project

While trackers have worked in collaboration with researchers, it has still not been possible for trackers to document data and conduct their own research independently. The main obstacle is the fact that the best traditional trackers often cannot read or write. To overcome this we designed a user interface for a touch-screen hand-held computer for people who cannot read or write.

Fig. 20: The CyberTracker icon interface design (Photo Rolex/Eric Vandeville)

The CyberTracker Software Project was initially developed to enable highly skilled expert trackers who cannot read or write to collect complex data in the field. The CyberTracker field computer project started in 1996 as an Honours project under Professor Edwin Blake at the Department of Computer Science at the University of Cape Town, South Africa (Edge, Foster and Steventon, 1996). After completing his Honors Degree in Computer Science, Justin Steventon and I founded CyberTracker in 1997 to develop free software for data capture in nature conservation. Receiving the Rolex Awards for Enterprise in 1998 gave us worldwide publicity, which resulted in a substantial grant from the European Union, co-funded by Conservation International. This grant enabled us to develop most of the core functionality of the CyberTracker software.

CyberTracker was field tested by trackers Karel Benadie and James Minye for almost three years in the Karoo National Park in South Africa. Although they cannot read or write, they have been using the field computer to record their observations in the field and download the data onto the PC by themselves. They have therefore demonstrated that they can use the computer independently.

The data they collect are very detailed. For example, shifts in rhino feeding behaviour can be seen every two months, shifting from the rainy season through to the dry season. In addition they record tracks of rare or nocturnal species that are not normally monitored. They record virtually everything that they find interesting in the field. This may make it possible to monitor long term trends that would not otherwise be noticed at all. Field tests indicated that a tracker can generate more than 100 observations in one day. They highest number was 266 observations in one day, and 473 observations over a three-day period. One computer could therefore generate more than 20 000 observations in a year.

Individual Rhinos can be identified by the distinctive random pattern of cracks that show up in their tracks. This allows trackers to track individual Rhinos and collect data on their behaviour and feeding habits. The movements of individual Rhinos are shown on a map. This shows areas frequented exclusively by each individual Rhino, as well as areas where their territories overlap. From an anti-poaching point of view, knowing where the Rhinos drink and sleep may help to protect them in the areas where they are most vulnerable, since these would be the locations where a poacher will most likely find them during the day. To optimise available manpower (there are at present not many women trackers in anti-poaching units), anti-poaching patrols can therefore cover those areas where poaching will most likely occur.

The field computer is designed to be quick and easy to use in the field, enabling trackers to record all significant observations they make. The field computer therefore makes it possible to generate a large quantity of very detailed data. Computer visualisation makes it possible for scientists to have instant access to all the information gathered over a period of time.

Icons allow the tracker to select options by simply touching the screen of a touch-screen handheld computer. The menu includes icons that enable the tracker to record sightings of animals, animal track observations, species, individual animal (such as individual rhinos), numbers of males, females and juveniles. Species covered may include a full range of mammals, birds, reptiles and other animals. Activities such as drinking, feeding, territorial marking, running, fighting, mating, sleeping, etc. can be recorded. A plant list enables the tracker to record plant species eaten by the animal. The tracker goes through a sequence of screens until all the necessary information is recorded. When the tracker saves the information an integrated Global Positioning System (GPS) automatically records the location of observations. With each recording the tracker (if he/she can write) also has the option to make a field note if he observes something unusual that is not covered by the standard menu. (An illiterate tracker can ask a literate apprentice tracker to write the field notes. Also, we recently added voice recording as an option).

When the tracker gets back to the base camp he follows a very simple procedure to transfer the data onto the base station PC. A simple query system allows the user to display observations for any selected period on a map. The user may query any level of detail corresponding to the information gathered by the trackers. The data is also quantified in the form of graphs and in a spreadsheet format. Standard statistical methods can be applied to analyse the data.

At the outset the point of departure was that the field computer system should not attempt to do what trackers can do, such as their ability to recognise and interpret very subtle signs in nature. Rather, the highly refined skills of the tracker should be recognised and the computer should enhance these skills and not attempt to replace them. In many fields computers tend to replace people. In contrast, the field computer was designed to empower people and enable them to extend their abilities. Rather than replacing human skills, it makes these skills more valuable.

Tracking involves the recognition and interpretation of natural signs. To make sense of these signs the tracker creates hypothetical models of animal behaviour that explains underlying causal connections between signs. The computer user interface consists of artificial signs (icons) which the tracker must recognise, select and connect with each other by navigating a path through a sequence of screens. The meaning of artificial signs (icons) corresponds with the tracker's interpretation of natural signs (animal tracks). The tracker therefore has a natural ability to connect a sequence of artificial signs corresponding with a sequence of natural signs. The field computer system uses the tracker's ability to interpret signs, thereby capturing a source of information about animal behaviour and ecosystems that were not previously available.

The field computer system not only enables trackers to communicate all their observations to the conservation manager on a day-to-day basis, but also stores the information over time long after the trackers may have forgotten the specific details. Long term ecological trends can therefore be monitored in much more detail than was possible before. Computer visualisation will make it possible to analyse vast quantities of data in a meaningful way.

The Tracker as Scientist

To the untrained eye the arid Karoo may appear lifeless and desolate. But for Karel Benadie it is full of signs of life. He is one of the rare master trackers who has a wealth of knowledge about animals and plants and a keen understanding of his part of the environment in the Karoo. As a young boy he herded sheep on the farm that eventually became the Karoo National Park, South Africa, where he started working at the age of thirteen. Twenty years later, in 1996, one of his duties was to track and monitor the rare Black Rhino. His knowledge of the local environment enabled him to track each individual rhino, which he could identify by their tracks, recording their movements, the plants they were feeding on, where they rested, where they were drinking, their activities and interactions. Along the way, while tracking one of the rhinos, he would often stop to inspect a hole to see what animal lived in it… a Yellow Mongoose, a Small Grey Mongoose, a Honey Badger or a Porcupine. He recorded sightings of herds of Kudu or Zebra, or a solitary Steenbok or a Duiker.

For each observation Karel deftly navigated a series of screens on the Apple Newton, a hand-held computer with a touch-screen that was wired to a Garmin GPS. Touching an icon to record the species, numbers of males, females, juveniles, what they were doing, what they were feeding on… and each time he saved his data, the date, time, latitude, longitude and altitude were captured with the integrated GPS. Eventually using the handheld computer became second nature to Karel – for him it had the familiarity of a box of matches – in as little as ten seconds he could capture up to ten fields of data, recording more than a hundred detailed observations in a day.

A few years before, while tracking with traditional !Xõ hunters, who still hunt with bow-and-arrow, in the Central Kalahari, Botswana, it occurred to me that if we could capture the observations of master trackers, it could be of great value to conservation and scientific research. However, the best trackers could not read or write. This is how we found ourselves in 1996 in the Karoo National Park, where software developer Justin Steventon developed a prototype of the icon-based user interface.

Karel Benadie cannot read or write. Even before we developed the CyberTracker, Karel told me that he thought it was a good idea, because it will enable him to show his knowledge of the wildlife. He pointed out that knowledge is always brought in by "expert" scientists who come from outside, but who do not know the environment as he does. For example, a rhino specialist (with a PhD) would come to the Karoo National Park once a year for ten days to study rhino feeding behaviour. But Karel maintained that rhinos feed on different plants during the wet and dry seasons – so if the rhino specialist only has data for the wet season, it does not show what the rhinos feed on during the dry season.

During the next year, together with fellow ranger and tracker James Minye (who also cannot read or write), they gathered detailed data on rhino behaviour, showing seasonal variation in feeding patterns through the year. Their rhino feeding data were published in the journal *Pachyderm* (Liebenberg, Steventon, Benadie and Minye, 1999). As far as we know, this was the first time that two non-literate trackers co-authored a paper (together with myself and software developer Justin Steventon) based on data that they collected themselves, independently with no supervision, to substantiate a hypothesis that they themselves proposed.

In the Western Kalahari in Botswana, wildlife biologists and local /Gwi and !Xõ trackers collected data for the Western Kalahari Conservation Corridor Project (WKCC) on the distribution patterns and population dynamics of wildlife in a corridor between two protected areas, the Kgalagadi Transfrontier Park and the Central Kalahari Game Reserve.

!Nate and Karoha were key players in the creation of CyberTracker. Ideas for developing CyberTracker came about through their involvement in researching the depth of tracking knowledge in the Kalahari. The two, especially Karoha, also played an integral role in its pilot testing. This is tremendously important to the trackers and has major implications in the way that they have incorporated this technology into their lives, to the extent that they have come to consider themselves ‘Cyber trackers’. !Nate takes pride in his involvement in the development of CyberTracker and is quick to mention it when discussing CyberTracker. The work that they did together led to the development of a technology that utilizes !Nate’s knowledge, while also recognizing that of his ancestors. The knowledge trails of his predecessors are present in the very existence of CyberTracker. Though he has had relatively little interaction with computers, he now has computer software designed specifically for his knowledge that is often regarded as an extension of himself (!Nate often referring to his ‘knowledge’ as his ‘CyberTracker’). CyberTracker owes its very existence to the world of tracking and, to a degree, has been embraced by the trackers as such. Pierre du Plessis (2010) notes that during his fieldwork it was immediately evident that all of the trackers take pride in calling themselves ‘Cyber trackers.’

Empowered by their role as data collectors, CyberTracker is a domesticated technology for the trackers of WKCC. It has become their own rather than just a tool of appropriation through the extension of a scientific and resource management network. As a tool that utilizes the knowledge of the trackers, it allows them to continue learning at a time when there would otherwise be little opportunity to practice their skills to such a degree. Karoha said, “I like CyberTracker because I am learning a lot. I like using the technology. I like that I can use it to track animals.” !Nate, Karoha, and Nxjouklau, three of the eldest trackers, often expressed their desire to teach and pass on their knowledge of animals and plant life. Working with, and teaching some of the younger trackers were in fact one of the aspects of the WKCC project that they valued most (du Plessis, 2010).

In addition, the trackers find security in that fact that CyberTracker stores the information they observe. Nxjouklau said that he likes using the CyberTracker because “if I have it in my hand I know the information will go to the people.” !Nate elaborated on this point: “One thing that I like is that it helps me capture the information. I like that what I see is being stored in the CyberTracker. I know that what I am doing will not disappear. If I don't have the CyberTracker there is no way I can store the tracks, but with it I can save the information." It is evident that the trackers themselves consider the data-archiving component extremely important (du Plessis, 2010).

Through the relationships established in the extension of networks in the WKCC project, both the trackers and the scientist, Moses Selebatso, were able to mention ways that they are learning, and therefore benefiting, from one another. A mutual appreciation and respect of knowledge has developed through their co-production of knowledge. The trackers are influencing the scientist's understanding of how to engage with the world and approach conservation. The trackers know things about the wildlife and have the practical skills to identify those things because of their experiences in the Kalahari that the scientists cannot. They offer WKCC a means through which they can have a much more in-depth and accurate data collection process (du Plessis, 2010).

By demonstrating that they could accurately enter complex field observations, these trackers showed that anyone, regardless of literacy or education, can make a contribution to science. If the art of tracking is the origin of science, then there is no reason why modern trackers, irrespective of whether they can read or write, should not be able to make a contribution to science.

The history of scientific progress is usually seen as a progression from crude scientific theories to more refined, sophisticated theories that strive towards a better approximation of reality. The most recent developments in science are usually seen as an improvement on previous theories. The emergence of modern tracking is an example of revitalizing an ancient science and integrating modern technology, resulting in practical modern day applications. Computers, scientific publications and formal qualifications may develop the art of tracking into a modern science. But at what point does tracking become a 'science'? When a modern tracker puts down his or her hand-held computer, is he or she no longer doing 'science'? These examples challenge us to reconsider the boundaries of science.

Revitalising Tracking Skills

In order to revitalize tracking skills, I initiated the Tracker Evaluation system in South Africa. But what was most significant is that of all the trackers who were evaluated over the years, Karel Benadie and James Minye, working with the CyberTracker handheld computer, showed the most rapid improvement in tracking skills. Karel explained that the CyberTracker helped him improve his tracking skills in two ways: In the past, he may have walked past a small hole, but with the CyberTracker he would stop to investigate the tracks going into the hole in order to record the observation. So the CyberTracker made him look at tracks and signs that he may otherwise have ignored. But the second reason is perhaps more inspiring – the CyberTracker motivated him to record all his observations, because he knew that one day his children will be able to see his work. So in addition to the Tracker certificates, which motivates trackers to improve their skills, the CyberTracker software also proved to be an effective tool to revitalize the art of tracking.

Perhaps the most significant benefit is the prestige that the field computer gives to trackers who previously were held in low esteem. In the Karoo National Park some of the staff commented that they did not know that Karel (who was seen as "illiterate" and therefore not intelligent) was so intelligent (because he "can use a computer"). Karel Benadie and James Minye found that using the field computer has given them an incentive to refine their skills and has made their work in the field more meaningful. For the first time they were recognised for the work they do. Creating employment opportunities for trackers in national parks provides economic benefits to local communities. In addition, non-literate trackers who have in the past been employed as unskilled laborers can gain recognition for their specialized expertise. The employment of trackers will also help to retain traditional skills, which may otherwise be lost in the near future.

In 2008 I conducted an evaluations of trackers employed in the WKCC project and was disappointed that !Nate and Karoha made mistakes that I did not expect them to make. In particular, !Nate mistook a perfectly clear Wild Dog track for a Brown Hyena track. He simply did not look at the track properly and gave his answer after glancing at the track from a distance. He correctly identified Wild Dog tracks in the week before this test and subsequently, so it is not that he did not know the track. He also identified extremely difficult tracks that were much more difficult, so it is not because of lack of skill. The mistake was due to carelessness and lack of discipline. The other three trackers identified it correctly and laughed at him for making such a mistake. !Nate himself immediately recognized his mistake and laughed at himself.

In 2010 I conducted a follow-up evaluation of !Nate, Karoha and Njoxlau, as well as /Uase Xhukwe (who was not selected for the WKCC project). The most significant result was that all four trackers excelled in the Track & Sign evaluation, not making any of the type of mistakes they made in 2008. !Nate in particular made a point of searching out the most difficult tracks and signs that he could find in order to show me what he can do.

It is clear that the disappointing results in 2008 were due to the trackers becoming rusty because they no longer hunted as often as in the past. After using the CyberTracker for scientific wildlife surveys over a two-year period, their tracking skills improved dramatically and were at the exceptional level that I observed ten to twenty years ago when they were hunting on a regular basis. The WKCC project therefore demonstrated the value of CyberTracker in revitalizing traditional tracking skills. In a sense the CyberTracker may replace the bow-and-arrow as the artifact that may sustain traditional tracking skills into the future. !Nate, Karoha, Njoxlau and /Uase were awarded the Traditional Master Tracker certificate in 2010.

CyberTracker in National Parks and Protected Areas

The Kruger National Park (KNP) in South Africa first recognised the potential use of the CyberTracker system as an ecological data collection tool in early 2000 and now uses 210 CyberTracker units to cover the entire park. The objectives of the CyberTracker system are not only to provide all section rangers with a tool for area-integrity-management but also to help provide answers to the various research questions, outlined as objectives and associated Threshold of Potential Concern (TPC) in the KNP Management Plan. The KNP's Adaptive Management Plan aims to provide a better understanding of the dynamic ecosystem of the national park (Kruger and Mac Fadyen, 2011).

From 2004 to 2006 the KNP CyberTracker data comprised over 1.97 million records with the entire KNP sampled at least once during this period. We know of no other data set with records for as many species with such a fine resolution over such an extensive area for any protected area in the world. An additional strength of the CyberTracker data set is the large number of records that may be used as absence data or null records in assessing and modeling species distributions (Foxcroft et al. 2009).

The field data collected with the CyberTracker KNP Ranger Diary system aims to benefit both the management and scientific research of KNP through the planning of section patrols for area-integrity management, acting as an early warning system for disease outbreaks, identifying trends in the exit and entry points of poachers, managing the control of invasive species and reporting fence breaks to veterinary department for animal health purposes. The data also feed into existing KNP projects incl. Wild dog Monitoring, Invasive species, Varroa mite/Honey Bee, Fire management system, Archaeological inventory, Establishment of rare game and carnivore distribution patterns and estimated totals etc.

Field rangers from each section in the KNP are deployed on a daily basis to patrol selected areas with up to four CyberTracker units. Observations are recorded throughout the patrols including the routes traveled and time taken. On the field ranger's return, the section ranger downloads the patrol data to his/her desktop CyberTracker Ranger Diary Database and reviews the observations of the day. At the end of every month each of the 22 section rangers exports their CyberTracker data for that month and the data to the Geographic Information Systems (GIS) Lab in Skukuza. The data is then collated, summarized and made accessible to all users through the KNP network.

The database was customised as an icon-based interface with English and Shangaan descriptions for the collection of the following lat/long data: Daily field ranger patrol information; Species distribution incl. Megaherbiovores, Ungulates, Carnivores, Small mammals, Birds and Reptiles; Location of various tracks including illegal human activity (poaching) and rare game; Available surface water including natural and artificial water; Location of diseased or injured animals and associated causes; Location of game carcass including possible cause of death; Location of all poaching activities with brief description of activity; Impact of elephants on specific sensitive tree species; Distribution of invasive species including terrestrial, aquatic and riparian; Fire mapping including burn scars, ignition points and active fires.

The extent of the use of CyberTracker in KNP is not only limited to the Ranger Diary system but includes a range of customised systems, which range from vegetation surveys to elephant behaviour studies. Some of the other systems include: Customized vegetation surveys for long-term ecological monitoring within fixed exclosures; Annual veld condition assessments, which not only emphases on the evaluation of grazing quality and quantity and fuel for burning also the broader evaluation of vegetation as a whole; Biodiversity/Habitat surrogacy surveys, which aims to predict the presence of certain species based on available habitat; Elephant translocation study, following elephant herds and recording various aspects about their behaviour, vegetation utilization and feeding methods; KNP archeological sites and associated artifact inventory; Small mammal mark-capture and release studies; Fire behaviour surveys on the long-term Experimental Burn Plots, which record information like wind direction and velocity during the fire, ambient temperature and relatively humidity, time taken to burn and the effect on the vegetation.

The full richness of the KNP CyberTracker data set will only emerge over time as the data are explored from a number of perspectives. Accurate absence data, such as provided by the CyberTracker data set, opens the door for advanced distribution modeling, and also provides a measure of the evenness of sampling, which is important for detecting small populations (Foxcroft et al. 2009).

The CyberTracker project in the Kruger National Park, which is being replicated in 21 other national parks as well as a number of provincial nature reserves in South Africa, shows the potential value to conservation – if this can be replicated in national parks throughout the world, it could have profound implications for conservation worldwide.

Towards a Worldwide Environmental Monitoring Network

From its origins in the Karoo, the Kalahari and the Kruger National Park, CyberTracker projects (www.cybertracker.org) have been initiated to monitor gorillas and forest elephants in the Congo rain forest, to track snow leopards in the Himalayas, for a butterfly census in Switzerland, monitoring of the Sumatran rhino in Borneo, tracking of jaguars in Costa Rica, bird surveys in the Amazon, to study wild horses in Mongolia, for monitoring by indigenous trackers in Australia, dolphin research in Southern California, survey of marine turtles in New Caledonia in the south Pacific, for a whale survey in Antarctica… CyberTracker is being used in national parks, scientific research, citizen science, education, forestry, farming, social surveys, health surveys, crime prevention and disaster relief. Distributing CyberTracker as freeware has allowed numerous independent initiatives to get off the ground, which we hope will result in unrestricted growth of environmental monitoring projects worldwide.

The CyberTracker data collected in the South African National Parks is shared with international data networks like DataONE, the Data Observation Network for Earth (http://www.dataone.org/). DataONE comprises a distributed network of data centers, science networks and organizations for open access to well-described and easily discovered Earth observational data.

CyberTracker is just one initiative amongst many, but it has demonstrated how participation in science can be broadened to include communities who were previously excluded from science. From small local projects to large scale international programmes, these initiatives each make a different contribution which may collectively work towards a worldwide environmental monitoring network.

In the near future intelligent machines may be able to discover patterns in complex data sets that humans can't. Intelligent machines will be able to think as much as a million times faster than the human brain. For example, such a machine may be able to predict weather patterns far better than humans. Putting large amounts of weather data into a form that humans can readily understand is difficult. An intelligent weather brain, in contrast, would sense and think about weather directly. These machines would not merely replicate human behaviour. Rather, they would be tools that will dramatically expand our knowledge of the real world (Hawkins, 2004).

Over time, technology will become more powerful and cost will be reduced. As the cost of smart phones is reduced over time, more and more people will be able to participate. As computers become more powerful, we will be able to process more data, and share data on a worldwide basis, even in the remotest wilderness areas. Increased awareness and participation can result in an exponential growth of data. Eventually it may be possible to integrate data from projects worldwide, creating the opportunity to monitor environmental change on a worldwide scale in real time.

Continuity in Science across Cultures

In conclusion, this chapter looked at practical applications of the art of tracking in a modern context. These examples demonstrate continuity between "indigenous knowledge" and modern Western science. It demonstrates the ease with which traditional trackers, who cannot read or write, can adopt and take ownership of modern computer technology. It shows how trackers can participate in a range of scales from individual, local through to global scales. It shows how traditional tracking can be combined with various other technologies and how modern tracking can be developed using statistical analysis. These examples break down barriers between conventional notions of "science" and "indigenous knowledge" and between literate and pre-literate cultures. Breaking down these barriers challenges us to redefine the boundaries of science.

11

Citizen Science

While the CyberTracker project demonstrates the potential value of employing trackers in conservation and scientific research, it also raises a more fundamental question. If hunter-gatherers were practicing scientific reasoning it is possible that it may have evolved by means of natural selection and that it may well be an innate ability.

Hunter-gathers do not go to university to learn about scientific methods. They have an innate ability to use scientific reasoning when they interpret tracks and signs and make testable predictions about animal behaviour. Since the evolution of modern humans, possibly more than a hundred thousand years ago, humans have been practicing science. This would imply that all humans, throughout history, would have been capable of scientific reasoning, irrespective of their culture. Scientific reasoning may well be innate to the human mind.

This may have far-reaching implications for citizen science and the democratization of science. If citizens have an innate ability to do scientific reasoning, there is no reason why citizens should not be able to participate in science in a more fundamental way. By adopting a broader, more inclusive understanding of what science is, our capacity to do scientific research can be expanded far beyond the narrow, elitist confines of academic science.

The Child as Scientist

A number of developmental psychologists have suggested that children engage in a process of theorizing analogous to scientific theorizing (Carey, 1985; Wellman, 1990; Gopnik and Meltzoff, 1997). While the "child-as-scientist" view has been debated by academics, perhaps the most convincing example is the publication of a scientific paper by 8- to 10-year-old children by The Royal Society. This example suggests that scientific reasoning is an innate ability developed in early childhood.

Blackawton Bees

Perhaps one of the most inspirational scientific papers was published by The Royal Society in the journal *Biological Letters*. This paper, "Blackawton Bees," describing an original discovery on the vision of bumble-bees, was designed, conducted, and written up by a group of 8- to 10-year-old children outside of London, UK. The study was guided by Dr. Beau Lotto and educator Dave Strudwick. The children asked the questions, hypothesized the answers, designed the games (the experiments) to test these hypotheses and analysed the data. They also drew the figures (in colour pencil) and wrote the paper. The paper was inspired not by the scientific literature, but by their own observations of the world. In a sense it reveals science in its truest (most naïve) form, and in this way makes explicit the communality between science, art and all creative activities (Blackawton, et al. 2010).

Their point of departure is that: "Knowing that other animals are as smart as us means we can appreciate them more, which could also help us to help them… We see bees in the natural habitat doing what they do, but you do not really see them doing human things—such as solving human puzzles like Sudoku. So it makes you wonder if they could solve a human puzzle. If they could solve it, it would mean that they are really smart, smarter than we thought before, which would mean that humans might have some link with bees. If bees are like us in some way, then understanding them could help us understand ourselves better" They further ask, and collect data to demonstrate it, if all the bees solve the puzzle in the same way. If not, they argue, it would mean that bees have personality. The children also show empathy for the bees: "No bees were harmed during this procedure" (Blackawton, et al. 2010).

Their principle finding is that: "We discovered that bumble-bees can use a combination of colour and spatial relationships in deciding which colour of flower to forage from. We also discovered that science is cool and fun because you get to do stuff that no one has ever done before (Children from Blackawton)." The project was funded privately by Lottolab Studio, as the referees argued that young people cannot do real science (Blackawton, et al. 2010).

It is perhaps interesting to note that this highly anthropomorphic approach essentially makes the same assumption as traditional trackers: the assumption that animals are like humans.

Citizen Science

Citizen science involves volunteers, regardless of education, in scientific research. The degree of involvement of citizens in science varies from a very basic level of participation through to the publication of original research in peer reviewed science journals. Citizen science can be broadly divided into two categories, Participatory Citizen Science and Independent Citizen Science. These categories, however, represent a continuous spectrum from the most basic through to the most advanced levels.

Participatory Citizen Science usually involves volunteers collecting data, following simple data collection protocols. Projects are initiated and managed by professional scientists, who also analyze and publish the data.

Projects may involve volunteers in varying degrees in the project design, data collection and data analysis. In some cases volunteers may be involved in all aspects of the research projects, working with professional scientists.

The earliest citizen science project of this type is probably the Christmas Bird Count that has been run by the National Audubon Society in the USA every year since 1900. In the UK, the British Trust for Ornithology was founded in 1932 with the express purpose of harnessing the efforts of amateur birdwatchers for the benefit of science and nature conservation. Citizen scientists now participate in projects on climate change, invasive species, conservation biology, ecological restoration, water quality monitoring, population ecology and monitoring of all kinds. (Silvertown, 2009)

In most cases citizens gather data, following simple procedures, and the data is then analyzed and interpreted by professional scientists (LeBaron, 2007; Bonney, 2008; Bonney et al, 2009; Gould, 2008; Wilderman, 2007). In these cases the citizens participate in science, but they themselves are not really doing "science."

In other cases citizen science has played a role in promoting science education (Bonney et al, 2009), ecological understanding (Jordan, 2008; Jordan et al, 2009) and to bridge the gap between science and political decision-making (Baillie, 2007; Vaughan, 2007; 2008).

There is no reason why citizens themselves should not be able to do science. Citizen science projects can be initiated and designed by citizens themselves. One model for citizen science involves a Community-based, Participatory Research Model, or "science by the people." This model is also called "Participatory Action Research." What this model attempts to do is have the community define the problem, design the study, collect the samples, analyze the samples, and actually interpret the data (Wilderman, 2007).

The Citizen Science Toolkit Project (www.citizenscience.org) provides guidelines, tools and resources that make it possible for volunteers to initiate their own projects. It is therefore in principle possible for volunteers to initiate citizen science projects with no involvement of professional scientists. Forums for citizen science also include www.scienceforcitizens.net and www.citizensciencealliance.org.

In contrast to Participatory Citizen Science, Independent Citizen Science consists of the publication of peer reviewed papers, in scientific journals, of original data and/or hypotheses. The independent citizen scientist may work independently, often alone with no funding, and do not necessarily have formal academic qualifications. Professional scientists only become involved during the peer review process when a paper or book is presented for publication.

Independent Citizen Science

In the 18th and 19th centuries amateurs played an important role in the development of modern science (Silvertown, 2009). During the 20th century science became professionalized and institutionalized, making it increasingly difficult for citizens to participate in science. Removing some of these barriers will allow the growth of independent citizen science.

I worked mostly in isolation for ten years, with no funding and no academic qualifications, before publishing my first books (Liebenberg, 1990a and 1990b), and then for another sixteen years before publishing my first peer reviewed papers (Liebenberg, 2006 and 2008) (I did do some other work in between). I found that the two most important factors in producing scientific publications are free access to a university library and to get critical peer review from professional scientists. If anything, rigorous criticism is even more important for the independent citizen scientist. Perhaps the most important advice to the enthusiastic young independent researcher is the words of Peter Medawar (1979): "the intensity of the conviction that a hypothesis is true has no bearing on whether it is true or not."

A Data-Centric Approach

A practical limitation would be gaining access to professional scientists who would be prepared to provide the necessary peer review. In particular, professional scientists would be reluctant to spend their time reviewing thousands of "theories" that simply have no basis in reality. To overcome this obstacle the citizen scientist need to build up credibility by first gathering solid, reliable data that can be used by scientists. A theory with no data to substantiate it is of no use to anyone, but good data can still make a contribution, even if the theory is wrong. Most citizen scientists, such as bird watchers, produce only data. A data-centric approach to citizen science would therefore be the best way to build credibility in order to gain access to professional scientists.

It should be noted that even good theories are not readily accepted by the scientific community. This is perhaps best illustrated by a remark made by Albert Einstein to the physical chemist Herman F. Mark, as reported to Holton (1986): "You make experiments and I make theories. Do you know the difference? A theory is something nobody believes except the person who made it, while an experiment is something everybody believes except the person who made it." Even though Einstein was a theorist, he spent most of his time as a student in the laboratory focusing on doing experiments in order to understand the meaning of empirical observations and was initially inspired by the physicist and philosopher Ernst Mach to follow an empiricist approach to science. In his early years, Einstein considered himself to be an experimentalist: "I worked most of the time in the physical laboratory, fascinated by the direct contact with experience." (Holton, 1973). Without the insights he obtained in the meaning of empirical observations, he would never have made his 1905 breakthroughs in the photoelectrical effect (for which he was awarded the Nobel Prize), Brownian motion and the theory of Relativity. To make a contribution to theoretical science, you first need to understand the meaning of empirical data.

One potential solution could be to create sections in scientific journals that are dedicated to data collected and papers written by citizen scientists (Jordan, pers. com.). While this may not be viable for paper editions, electronic editions could provide unlimited space to publish data. This could provide a first stepping stone or a bridge for new citizen scientists to get their data published. Critical feedback from professional scientists and critical discussion with other citizen scientists would provide them with practical experience, helping them to develop the ability to publish papers in peer reviewed journals.

The Authority of Science

The most influential and dominant tradition among modern scientists in the approach to scientific theories is *elitism*. According to this view, the layperson or outsider cannot understand and therefore cannot appraise scientific theories. Only a privileged scientific elite can judge their own work. Within the scientific elite there is an authority structure, which means that the scientific community is predominantly authoritarian in its appraisal of scientific theories (Lakatos, 1978b). Although authoritarian elitism may be the dominant tradition among modern scientists it should be pointed out that it is by no means the only school of thought. Skepticism, including Feyerabend's (1975) "epistemological anarchism," denies that scientists can have any authority to appraise theories. *Philosophical skepticism* regards scientific theories as just one belief-system which is epistemologically no more "right" than any other belief-system. *Rational skepticism*, on the other hand, maintains that scientific reasoning is a method leading to provisional conclusions (Shermer, 1997). *Demarcationism* holds that there exist criteria which allow the educated layperson to demarcate science from non-science, and better from worse knowledge (Lakatos, 1978b).

A further characteristic feature of modern science is the authoritarian practice of education. Knowledge is presented in the form of infallible systems based on conceptual frameworks that are not subject to discussion (Lakatos, 1978b). Science students accept theories not on the basis of evidence, but on the authority of teachers and textbooks. Until the very last stages in the education of a scientist, textbooks are systematically substituted for the creative scientific literature on which they are based. The student does not have to read the original works of pioneer scientists of the past. Rather, everything the student needs to know, as far as his/her education is concerned, is recapitulated in a far briefer, more precise, and more systematic form in a number of up-to-date textbooks. This type of education has been very effective for normal-scientific work (such as puzzle-solving) within the tradition defined by the textbooks. But this type of scientific training is not well designed to produce the scientist who will easily discover a fresh approach (Kuhn, 1962).

In contrast to the relatively authoritarian nature of modern scientists, hunter-gatherers are much more egalitarian. Even young trackers may, for example, disagree with their elders and propose alternative interpretations of tracks. The learning process in tracking differs once again in that it is an informal, dynamic process of continuous problem-solving. Even from childhood, the young tracker is exposed to the scientific process. Recently, many mentorships at universities are providing a more egalitarian approach to education (Jordan, pers. com.).

The authority of scientific argument does not lie in personal persuasiveness or in personal position but is independently available to anyone (Holton, 1973). The extent to which scientists rely on their position or personal persuasiveness, they are resorting to *irrational authority* and authoritarianism. Conversely, when a scientific argument is dismissed because the author lack a position or qualification in formal science, rather than on the rational scientific merit of the argument, then the dismissal would also be based on irrational authority. For scientific argument to be independently available to anyone, and therefore rely on *rational authority*, science requires a level of transparency that would enable a citizen who is sufficiently motivated to gain full and free access to all the scientific literature. This would include introductory texts that would guide the citizen scientist towards a full understanding of a scientific theory.

In practice the ideal of rational authority is not always easily achieved. It may sometimes be necessary to resort to irrational authority in order to achieve rational authority. For example, the independent citizen scientist may require endorsements from recognized experts, or "authorities," otherwise their work may never be noticed (hence the need for endorsements of this book). Relying on the authority of recognized experts resorts to irrational authority to draw attention to a novel theory. However, once a theory has gained wider recognition based on endorsements, it should then rely on rational authority to establish its scientific credibility.

Even if it should be in principle possible for the independent citizen scientist to publish new theories (as Einstein did), in practice it may be necessary to first subject a paper to rigorous peer review by professional scientists before submitting it for publication.

Role Models in Independent Citizen Science

Some of the best known independent citizen scientists in history include Charles Darwin, Rachel Carson, Jane Goodall and Albert Einstein.

Charles Darwin

Having benefited from inherited wealth Charles Darwin never had to pursue a career, giving him complete academic freedom to explore his own ideas. As a boy he felt that "the school as a means of education to me was simply a blank." At Edinburgh Medical School he spent his time reading extracurricular texts on the latest scientific, medical and political literature when he should have been at lectures. He did everything but work on his official studies and left Edinburgh without a degree. He finally graduated from Cambridge for a career in the clergy, which never materialized (Gribbin and White, 1995). In his sixties, he reflected that: "I consider that all I have learnt of any value has been self-taught" (Robinson, 2010).

Darwin's invitation to join the Beagle was primarily to keep Captain FitzRoy company. The trip was scheduled to last three years and the Captain needed to have a companion who was intellectually stimulating. Darwin's role as ship's naturalist was of secondary importance (Gribbin and White, 1995).

Darwin's theory took many years to develop fully and for most of the time he worked in secrecy, fearing that his ideas were too volatile for the time. He was predominantly a loner, working in solitude, unable to discuss his ideas with other scientists. He knew of no one he could really trust who would understand his theories and analyze them with an open mind. Only later, when he met Joseph Hooker, did he find a man who was a combination of professional companion and personal friend, a man in whom he could confide his most secret and radical ideas (Gribbin and White, 1995).

Rachel Carson

Rachel Carson saw it as her mission to share her observations with a wider audience. In the 1930s there were few professional opportunities for women in the sciences. She found a job writing radio scripts for the United States Fish and Wildlife Service. She also wrote freelance articles about the natural world for magazines and in 1941 published her first book, *Under the Sea-Wind*. In 1951 she published *The Sea Around Us*, a wide-ranging history of the ocean, which was an instant best seller. The book's success enabled her to leave her position at the wildlife agency and devote herself to writing, working full-time on *Silent Spring* as an independent citizen scientist. (Koehn, 2012)

Frustrated by a series of illnesses, including cancer, Carson's writing was at times interrupted by the "nearly complete loss of any creative feeling or desire." In 1964, two years after publishing her seminal book, she died of cancer at the age of 56. Scientists like E.O. Wilson have credited *Silent Spring* with a pivotal role in starting the modern environmental movement. Rachel Carson is a forceful example of one person's ability to incite positive change. (Koehn, 2012)

Jane Goodall

When she was twenty-six, Louis Leakey sent Jane Goodall into the field to study chimpanzees. She had no scientific training and had not been to university. She made three observations that challenged conventional wisdom in physical anthropology: meat eating by chimps (who had been presumed to be vegetarian), tool use by chimps (in the form of plant stems probed into termite mounds), and tool making (stripping leaves from stems), something thought to be unique to humans. Each of these discoveries narrowed the perceived gap of intelligence and culture between humans and chimpanzees, marking a very important new stage in thinking about what it means to be human (Quammen, 2010).

Goodall regards her most significant contribution to be the breaking down of the sharp line between humans and other creatures. Chimpanzees have helped people understand that we are part of and not separated from the animal kingdom, and that has resulted in people having respect for the other beings with whom we share the planet (Wong, 2010).

Goodall set a new standard for behavioral studies of apes in the wild, focusing on both individual characteristics as well as collective patterns. Once enrolled at Cambridge, she found herself at variance with conventional academic thinking. Her field data, gathered through patient observation of individuals she knew by names, came under criticism. Such personification that ascribed individuality and emotion to nonhuman animals was dismissed as anthropomorphism, not ethology. However, she maintained that "You cannot share your life in a meaningful way with any kind of animal with a reasonably well-developed brain and not realize that animals have personalities." (Quammen, 2010)

In order to fund and perpetuate her work she institutionalized her field camp as the Gombe Stream Research Centre. Since 1975 the responsibility for data collection was given to the Tanzanian field staff who functioned as trackers, helping to locate the chimps, identifying plants, and making sure that the white researchers got back to the camp safely (Quammen, 2010). Local trackers were therefore given a fundamental role in the ongoing research programme which has continued uninterrupted for 50 years.

Albert Einstein

Although it was theoretical physics which attracted Albert Einstein as a student, the physics course at the Swiss Federal Polytechnic School was designed primarily for engineers. It taught nothing of Maxwell's theory of electromagnetism, a theory that was symptomatic of the radically new ideas which were about to transform physics. Instead, Einstein pursued his real education by studying at home in his spare time (Clark, 1973).

What is perhaps most significant is that one of the books that Einstein studied was *Introduction to Maxwell's Theory of Electricity* by August Föppl (Holton, 1973). Föppl placed special emphasis on laying the foundations carefully, thereby accommodating readers who might not have had the benefit of formal lectures and whose formal background might have bad gaps. The book was written as an exposition of Maxwell's theory that would be as widely understandable as possible, but also scientifically correct.

Einstein obtained his Ph.D. at the University of Zurich, but it was touch and go whether he got his doctorate (Clark, 1973). His first regular job was at the Swiss Patent Office, where he felt free from the pressures to produce results.

Pioneers and visionaries often work in isolation, and in that sense the work of Einstein was very much the product of a man who had sought solitude all his life. Newton and Darwin showed very much this propensity towards isolation (Feuer, 1982). It could be argued that it was *because* Einstein was an independent citizen scientist that he enjoyed the freedom to explore new ideas. Einstein advised people not to connect their research with their profession. Research has to be free from the pressures which professions are likely to impose (Born-Einstein Letters, as quoted in Feyerabend, 1975). In other words, conducting your research as an independent citizen scientist allows you to enjoy complete academic freedom.

It should be noted, however, that freedom and independence does not guarantee success. It is quite likely that at the time that Einstein was working in the Swiss patent office, there may have been thousands of other potential Einsteins out there, with perhaps the same level of creativity, ingenuity and passion as Einstein, but who simply failed.

Charles Darwin retreated to the English countryside to find the room to think through an idea that obsessed him. Einstein spent ten years thinking about the ideas that became special relativity, and then spent the next ten years inventing general relativity. Time and the freedom to think are all that the visionary needs to solve an unexamined assumption. For visionaries, the need to be alone, working in isolation for an extended period at the beginning of a career is essential (Smolin, 2006).

Darwin, Carson, Goodall and Einstein were clearly exceptions to the rule, but they do demonstrate the potential contribution of independent citizen scientists. The degree of involvement in science can range from a bird watcher recording a single sighting or the publication of one or two peer reviewed papers, through to ground breaking theories at the most fundamental levels of science.

12

The Future

Fifty years ago Rachel Carson published her seminal book *Silent Spring* (1962) in which she warned of the unintended consequences of the indiscriminate use of insecticides on human health and the environment. This book is widely recognized as one of the greatest influences that inspired the environmental movement. In spite of sounding the alarm, however, environmental issues have grown more serious and more urgent.

Given a perspective of science evolving over hundreds of thousands of years, the next 50 years is a mere blink in time. Extrapolating the logistic growth of science into the future suggests that the next 50 years may well see an explosion of innovation in science and technology. But this brief period may well increase the risks of unintended negative consequences of unconstrained technological development. It highlights both the urgency and risks of promoting scientific innovation at a time that may be critical for the survival of humankind.

To solve problems we face over the next fifty years, young scientists need to pursue their passion for science regardless of whether or not they have access to funding and resources. The burgeoning growth of self-education and citizen science may have far-reaching consequences for the future of scientific innovation. However, our passion for science needs to be tempered by ethics and compassion.

Using Technology to get People back in Touch with Nature

While hunter-gatherers lived in nature and enjoyed a very direct experience of reality, people who live in cities are increasingly alienated from nature and in a very real sense from reality itself. Television, computers and the Internet give us access to a huge amount of information. But today most people live in cities, surrounded by an artificial urban environment. In a very fundamental way technology can alienate people from nature. Their perception of nature is limited to the perspectives offered by the media. Children growing up in cities are spending less time playing outdoors and more time indoors watching TV, playing computer games and interacting with people by means of social networking through the Internet (there is even a new word for it – "sofalising"). This has raised concern that children may suffer from "nature-deficit disorder" (Louv, 2006).

Martin Rees (2011) points out that Newton, when young, made model windmills and clocks, which represented high technology of his time. Darwin collected fossils and beetles. Einstein was fascinated by the electric motors and dynamos in his father's factory. But today, the gadgets that young people use on an everyday basis, such as smart phones, are baffling 'black boxes' which are indistinguishable from pure magic. Even if you take them apart you'll find few clues to their arcane miniaturized mechanisms. And you can't put them back together again. There is now, for the first time, a huge gulf between the artefacts of our everyday life, and what a single expert, let alone a child, can comprehend.

Taken to an extreme, one can imagine a child growing up in a space station immersed in a completely artificial environment. Even gravity would be artificial and could be adjusted by increasing or decreasing the rotation of the space station. The child may have full access to the Internet (or the Cloud), learning about Earth from nature documentaries, science programs and the best university libraries. At the same time, the child would also have full access to computer games, fiction, and life-like 3D movies like Avatar. But the child would have no real-world experience of what it is like to live on Earth. With no real-world experience and no empirical observations to distinguish what is reality or not, it may be impossible for such a child, when reaching adulthood, to distinguish reality from fiction. Many children growing up in cities, who have very little direct contact with the natural world, may be well on their way to becoming hypothetical "space-kids" – unable to distinguish reality from fiction.

The only way to get a more realistic understanding of nature is for people to go into wilderness areas and literally get in touch with nature. Paradoxically, technologies like iSpot (www.ispot.org.uk) and CyberTracker (www.cybertracker.org) makes use of cutting edge technology to get people back in touch with nature itself. iSpot makes it easy for citizens to submit photos of species in surveys. In the USA projects such as NatureMapping, BioKIDS and BioBlitz are using CyberTracker to enable volunteers of all ages to collect biodiversity data. In BioKIDS, inquiry-focusing technologies such as CyberTracker are used to promote conceptual understanding of science and scientific reasoning (Songer, 2006; Parr, Jones and Songer, 2002).

Using smart phones to collect data in citizen science projects, the "Gameboy" factor can be used to bring people back in touch with nature. Allowing people to view their own data on the Internet also helps to develop interactive participation on a global level. At a time when people are becoming increasingly alienated from nature, technology can be used to involve people of all ages across a wide range of interests and cultures to participate in citizen science on a global level.

Self-Education and Free Access to Scientific Literature

To develop independent citizen science to its full potential requires a level of transparency that need to fulfill the following criteria: Can a citizen with no prior experience in science, but who is sufficiently motivated, study freely available texts and data in sufficient detail and depth to make a meaningful contribution to the science?

Some of the most important scientists in history were also very good at explaining their ideas in simple language that can be understood by the lay person. Charles Darwin's *On the Origin of Species* is very well written and one of the few original scientific publications that can be understood by lay persons. Albert Einstein (1920) wrote one of the clearest simple language expositions of Relativity Theory. Einstein was not only a profound scientist, but also a popularizer, teacher, and philosopher-scientist. He took this role as a public educator very seriously and tried his utmost to write clearly and at a level where the intelligent lay person would understand him (Holton, 1986). Today writers like Edward O Wilson, Steven Pinker, and Stephen Hawking has written books on science that has captured the imagination of readers worldwide. Explaining science in simple language is essential to promote public understanding of science.

Free online self-education resources are growing exponentially. Search engines such as Google Scholar and Google Books makes research for sources very efficient. Wikipedia, Wikibooks and Wikispecies now give us free access to basic knowledge. The Khan Academy (www.khanacademy.org) provides free video tutorials for science and mathematics education. The growing network of The Open University (www.open.ac.uk), Wikiversity and the Open Courseware Consortium (www.ocwconsortium.org) provides university courses available free online. Harvard and M.I.T. have teamed up to offer free online courses with edX.

However, a serious barrier to self-education is the cost of subscription required by many of the best university libraries, something that is limiting the potential of science itself. Scientific research, journals, and data should be freely available to everyone. Ideally scientific works should be published under legal tools such the Creative Commons (http://creativecommons.org/). Already the Public Library of Science is providing journals like *Plos One*, an inclusive, peer-reviewed, open-access resource that is free to everyone.

Scientific papers are often notoriously inaccessible, even to professional scientists working in closely related fields. If you are not familiar with the current jargon, you have no hope of understanding what the authors are trying to say. If scientific papers had concise abstracts written in simple language, the growth of science itself would benefit. If ideas were explained in language that can be understood by intelligent lay persons, it would benefit professionals in other scientific disciplines as well. Often scientific breakthroughs are made when ideas from one discipline are introduced into another discipline.

In addition, texts need to be developed that would guide readers through different levels of understanding. One of the greatest challenges would be overcoming the barriers created by the necessary reliance of metaphors that are specific to specialized fields of science. The necessities forcing scientists to use metaphors in their work become handicaps for students who are not familiar with the use of these metaphors (Holton, 1986). Metaphors may be effective tools for scientists, but they create formidable barriers for students.

Even the best texts may still require at least some level of social interaction in order to translate the meaning of texts to individual students coming from a multitude of unique cultural backgrounds and experience. Each student has a “metaphor background” and “metaphor readiness” (Holton, 1986). Professional scientists would therefore need to become actively involved in citizen science. Even if professional scientists cannot personally interact with all citizen scientists, at least some of the citizen scientists would then be able to mentor other citizen scientists.

While Einstein worked in solitude, fields such as Quantum theory required the contributions of many physicists collaborating in teams. Today it seems that it is much harder for individuals to make substantial progress than it had been in Einstein’s day. Yet Roger Penrose (2004) feels that something more like the Einsteinian "one-person" approach may be needed to make fundamental breakthroughs in areas like quantum gravity.

Penrose points out that there is an enormous quantity of observation data in physics that still needs to be made sense of. Data from modern experiments are often stored automatically, and only a small particular aspect of that stored information may be of interest to the theorists and experimenters who are directly involved. If independent citizen scientists could have free access to experimental data, it is quite possible that new discoveries may be made, in the same way that citizen scientists are making discoveries in astronomy.

Lee Smolin (2006) also argues that deep, persistent problems are never solved by accident – they are solved only by individuals who are obsessed with them. These are the visionaries who are highly independent and self-motivated individuals who are so committed to science that they will do it even if they can't make a living at it. They can be recognized by their rejection of assumptions that most people believe in and take for granted. They are driven by nothing except a conviction that everyone else is missing something crucial. Their approach is scholarly in that to think clearly they have to read through the whole history of the question that obsesses them. Their work is intensely focused, yet it takes them a long time to get somewhere. It may require years of isolation engaged in scholarly self-education. The need to be alone for an extended period at the beginning of a career, and often in later periods, is essential.

If all scientific data can be made available on a free open-access basis to citizen scientists it is quite possible that isolated individuals may make significant contributions to science. For every potential Einstein who may succeed, however, thousands of would-be citizen theorists will probably fail. But the occasional citizen breakthrough may make a significant contribution to science at little cost to society. And since they will be driven by their own passion, even those who do not make a major contribution will derive satisfaction from the enjoyment of scientific discovery - the pursuit of knowledge for the sake of knowledge.

Unintended Consequences

Hunter-gathers survived periods of severe climate change over hundreds of thousands of years and were therefore very successful from a natural selection point of view.

There is, however, no guarantee that modern human populations will develop sustainable models of subsistence and history is littered with civilizations that over-extended themselves and collapsed (Diamond, 2005). It remains to be seen (or not to be seen, if there is no one left to see) whether modern Western science will survive even just a few hundred years. Bill Joy (2000) and Martin Rees (2003) warn that there are a number of scientific and technological developments that could threaten the very survival of humans in the twenty-first century. These include nuclear war, the loss of biodiversity, climate change and that genetics, nanotechnology, and robots may develop uncontrollably at the expense of humans.

In his book *Why Things Bite Back* (1996) Edward Tenner shows how new technological solutions often lead to paradoxical and unintended consequences that no one anticipated. Technology demands more, not less human work and vigilance. Antibiotics may promote more virulent bacteria. Pest-control may spread more resistant pests.

Tenner argues that technological optimism means in practice the ability to recognize bad surprises early enough to do something about them. And that demands constant monitoring of the globe, for everything from changes in mean temperatures and particulates to traffic in bacteria and viruses. We need to move ahead but must always look back because reality is always gaining on us. As the Red Queen said in *Through the Looking-Glass*: “Now, here, you see, it takes all the running you can do, to keep in the same place.”

We should never lose sight of the fact that science is fundamentally fallible. Yet we have no better option. Given the necessity to innovate, the freedom required for creative innovation need to be tempered by instilling a sense of ethics and morality.

Ethics and Morality in Science

Edward O. Wilson (2002) points out that science and technology determines what we can do, but ultimately it is morality that determines what we agree we should do. A conservation ethic is that which aims to pass on to future generations the best part of nature. To know it well is to love it and take responsibility for it.

Ethics is often seen as a choice. However, this would create the paradox of why ethics would have evolved in the first place. I would argue that once humans developed the capacity to over-exploit nature, ethics became a necessity for survival.

Hunter-gatherers did not, as Al Gore (2009) claims, only "respond quickly when [their] survival was at stake" in ways that were "often limited to the kinds of threats our ancestors survived: snakes, fires, attacks by other humans, and other tangible dangers in the here and now." Or, as Paul and Anne Ehrlich (2013) claim: "Until very recently, our ancestors had no reason to respond genetically or culturally to long-term issues… The forces of genetic and cultural selection were not creating brains or institutions capable of looking generations ahead; there would have been no selection pressures in that direction. Indeed, quite the opposite, selection probably favoured mechanisms to keep perception of the environmental background steady so that rapid changes (e.g. leopard approaching) would be obvious." On the contrary, hunter-gatherers planned for the future in times of drought and scarcity to ensure that animal and plant foods were not over-exploited.

/Dzau /Dzaku of Grootlaagte and independently !Nam!kabe Molote of Lone Tree in Botswana explained to me a conservation ethic practiced by Kalahari hunter-gatherers. During periods of drought plant foods would be scarce. If a particular plant was scarce, they would not exploit it, but leave it so that the population can grow back again. This meant that they had to hunt more animals to survive. In addition to animals dying due to the drought, hunters would have killed more animals, thereby reducing animal populations. After the first good rains, when plant foods recovered, they would then stop hunting to allow animal populations to recover.

What is significant about this tradition is that it required all hunter-gathers to co-operate on a voluntary basis over a large area. It is not something that they could force others to do and if some cheated it would not work. It required ethics to maintain this tradition for the benefit of all bands living over a large area of the Kalahari. The success of this tradition is demonstrated by the fact that the San hunter-gatherers are genetically amongst the oldest modern humans (Tishkoff, et al, 2009; Henn, et al, 2011) and continued to live as hunter-gatherers until the 1950's. Over a period of perhaps two hundred thousand years or more, the animals and plants they depended on were not driven into extinction by human over-exploitation.

Increasingly, scientists are discovering that there is a morality that science demands of itself. About one-third of the world's scientists and engineers work directly or indirectly on military matters, at a time when world affairs are becoming increasingly irrational. The increasing philosophical concerns with morality in science may indicate a growing awareness that scientific innovation is not in danger, but that humanity is (Holton, 1986).

History has shown that there will always be individual scientists, private corporations and even rogue states that will pursue science with no consideration for ethics or morality. Given the increased risks posed by potential negative consequences of technology, it is becoming increasingly important to not only monitor new developments in science, but to instill a sense of ethics and morality in young scientists.

Science is not just about empiricism or rationalism. The success of science is not only defined by its ability to make novel predictions about reality, but also depends on ethical and moral choices about whether these predictions should be pursued. Ethics and morality is a necessity for survival. Natural selection *requires* us to integrate ethics and morality into science and to consider the implications of science for human welfare, failing which humans may well go extinct.

Empathy and Compassion

I asked Bahbah, a !Xõ tracker from Ngwatle Pan, Botswana, what his feelings were towards animals. He explained that although he does have sympathetic feelings for the animals he kills, he, as a hunter, must eat. He does not feel sorry for an adult antelope, because it is food and it knows that it must avoid hunters. But if a juvenile antelope is caught in his snare, he feels very sad, because it is still very small and does not know anything. His feelings of sympathy even extended to arthropods. He explained that if he sees a beetle with one broken leg, he will feel sorry for it. But he does not feel sorry for a scorpion when he kills it, because it will not feel sorry for him if it stings him.

One morning after he had killed a gemsbok, Bahbah pointed out fresh gemsbok tracks close to the kill site. With a rather sad expression on his face, he explained that it was the tracks of the killed gemsbok's companion. He further maintained that because they grew up together, the gemsbok would always come back to that spot to look for its lost companion. The sympathetic way in which he told this story brings home the inevitable contradiction created by the way the tracker identifies himself with his quarry. In the process of tracking down the animal, the tracker develops a sympathetic relationship with the animal, which he then kills.

We need to maintain the fine balance between science and compassion. Creativity requires empathy, but once a hypothesis is conceived it is subjected to deductive reasoning and empirical tests in a *dispassionate* way. However, as Philip Davis and Reuben Hersh argue in *Descartes Dream* (1986), mathematical abstraction can be fundamentally dehumanizing.

Abstraction and generalization are two characteristic features of mathematical thinking. Abstraction is the source of great benefit and also the source of potential damage. The damage derives from the self-deception that one has discovered the essence of the larger whole. Abstraction is extraction, reduction, simplification, elimination. Such operations must entail some degree of falsification (Davis and Hersh, 1986).

Whenever anyone writes down an equation that explicitly or implicitly alludes to an individual or a group of individuals, whether this be in economics, sociology, psychology, medicine, politics, demography, or military affairs, the possibility of dehumanization exists. Whenever we use computerization to proceed from formulas and algorithms to policy and to actions affecting humans, we stand open to good and to evil on a massive scale. The spirit of abstraction and the spirit of compassion are often antithetical. What is not often pointed out is that this dehumanization is intrinsic to the fundamental intellectual processes that are inherent in mathematics (Davis and Hersh, 1986).

Science cannot be completely "objective" and dispassionate, since it risks becoming dehumanizing. Just as hypothetico-deductive reasoning involves interplay between the imagination and observation, at another level it also involves interplay between subjective empathy and objective observation. And at a more subtle level it involves interplay between cognitive empathy and emotional empathy. For science to be *humane* it also needs an element of compassion and ethics.

The interplay between cognitive empathy and emotional empathy is inherent in the "sympathetic understanding" (Einstein, 1954) required to create a hypothesis (see Chapter 8). When you create a novel hypothesis, the feeling of elation is an intensely emotional feeling, it is not a dispassionate calculation. This is why we feel so intensely passionate about our own theories, and sometimes fail to recognize, as Peter Medawar (1979) points out, that the intensity of the belief that our theories are true bares no relation to whether or not they are true.

Anthropomorphic projection, which involves empathy, is essential in creative thinking in science (see Chapter 8). Once a hypothesis is created, however, it needs to be tested by dispassionate, objective empirical data. But the outcome of this process then needs to be subjected to ethics, which involves compassion. In addition to the interplay at a logical level, science also involves interplay between subjective empathy and dispassionate objectivity.

With emphasis *only* on dispassionate objective empirical data, which is what logical positivism and Machian empiricism aimed to achieve, science would not only lack the creativity to produce novel hypotheses, it would also risk becoming destructive and dehumanizing. With emphasis *only* on subjective empathy, we have no objective way to test science against reality, and we may end up with wrong theories (superstitions and irrational beliefs), which could have disasterous consequences for humanity.

In *Silent Spring*, Rachel Carson describes the death of a squirrel from insecticide poisoning: "Even more pitiful was the mute testimony of the dead ground squirrels, which exhibited a characteristic attitude in death. The back was bowed, and the forelegs with the toes of the feet tightly clenched were drawn close to the thorax… The head and neck were outstretched and the mouth often contained dirt, suggesting that the dying animal had been biting at the ground. By acquiescing in an act that can cause such suffering to a living creature, who among us is not diminished as a human being?"

Unlike empirical knowledge, creative science not only involves rational, empirical and thematic components, it also involves an element of empathy that not only makes it an essentially *human* activity, but also a *humane* activity. For science to be humane and benefit humanity therefore requires a balance between subjective empathy and dispassionate objectivity.

The Citizen Science Movement

Although the roots of citizen science go back to the very beginnings of modern science itself, projects that involve citizen scientists are burgeoning (Silvertown, 2009). If enough young people can dedicate themselves to pursuing innovative solutions in science and technology, there may be enough innate creative potential to solve the most important problems we face in the near future.

However, irrespective of whether working as a professional scientist or an independent citizen scientist, it may take ten years of hard work and practice before attaining the high level of performance that results in great creativity. Not even Darwin or Einstein was able to short-cut the long and gradual path to creative breakthroughs (Robinson, 2010). The ten-year rule for creative breakthroughs makes it even more urgent that we encourage more young people to commit themselves to citizen science.

Both participatory as well as independent citizen science should become natural extensions of science as a whole. Throughout history, there was continuity from the ancient origin of science through to modern science. Similarly, there is continuity in the roles that can be played by professional through to independent citizen scientists. And even the most ancient science, the art of tracking, still have a small role to play in the future.

Creating conditions conducive to self-education and independent citizen science may unleash the innate creative potential of young people determined to secure their own future. Ultimately, the more independent initiatives we have, the greater the chances that some will make fundamental breakthroughs that could solve the problems we face in the near future. Working without funding and driven by their obsessional passion, large numbers of citizen scientists could make a significant contribution to science at very little cost to society.

Perhaps the greatest challenge for the future will be to allow the freedom necessary for creative innovation while maintaining ethics and morality to avoid unintended negative consequences. In addition, scientists can no longer claim to be dispassionate and objective - empathy and compassion is a necessity for science to be a humane activity.

CyberTracker

CyberTracker Conservation

The research and ideas presented in this book resulted in the formation of CyberTracker Conservation NPC, a non-profit organization whose vision is to promote the development of a Worldwide Environmental Monitoring Network.

Climate change, pollution, habitat destruction and loss of biodiversity may have serious impacts on human welfare. To anticipate and prevent negative impacts will require ongoing long-term monitoring of all aspects of the environment. Our mission is to help communities to monitor their own environments.

From its origins with the Kalahari trackers, CyberTracker projects have been initiated to monitor gorillas in the Congo, snow leopards in the Himalayas, butterflies in Switzerland, the Sumatran rhino in Borneo, jaguars in Costa Rica, birds in the Amazon, wild horses in Mongolia, dolphins in California, marine turtles in the Pacific and whales in Antarctica.

CyberTracker is being used in indigenous communities, national parks, scientific research, citizen science, education, forestry, farming, social surveys, health surveys, crime prevention and disaster relief.

CyberTracker is the most efficient way to gather large quantities of geo-referenced data for field observations, even by non-literate users, at a speed and level of detail not possible before. Involving scientists and local communities in key areas of biodiversity, CyberTracker combines indigenous knowledge with state-of-the-art computer and satellite technology. Public participation in ongoing monitoring will also help to develop environmental awareness.

Our ultimate vision is that smart phone users worldwide will use CyberTracker to capture observations on a daily basis. Data streaming into the Internet (the Cloud) will make it possible to visualise changes in the global ecosystem in real time.

By providing free data capture software and a methodology to improve observer reliability we hope to broaden the boundaries of science, ultimately working towards the democratization of science.

CyberTracker was awarded the Rolex Award for Enterprise.
Patron: Edward O. Wilson, Harvard University
www.cybertracker.org

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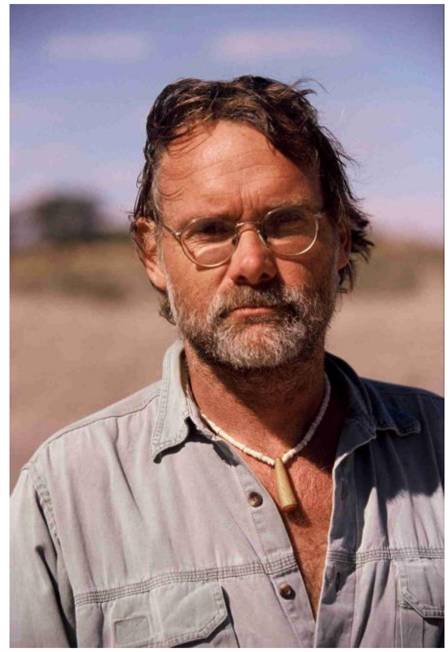
About the Author



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Papers published include: "The Relevance of Persistence Hunting to Human Evolution," 2008, *Journal of Human Evolution*. 55: 1156-1159; "Persistence Hunting by Modern Hunter-Gatherers," 2006, *Current Anthropology*. 47:5; and "Rhino Tracking in the Karoo National Park," 1999, co-author with Lindsay Steventon, Karel Benadie and James Minye, *Pachyderm*, Number 27.

Represented the ANC in 1993/94 in the International Mission on Environmental Policy to write the report on *Environment, Reconstruction and Development*, with a forward by Nelson Mandela, edited by Anne V. Whyte. Published in 1995 by the International Development Research Centre, Ottawa, Canada.

Conducted extensive field research since 1985 with traditional trackers of the Kalahari in Botswana and Namibia. Developed practical tracking skills since 1980 to a high level of sophistication. Tracking skills include the ability to accurately identify tracks and signs (including arthropods, amphibians, reptiles, birds, and small to large mammals) throughout southern Africa, tracking rhino, lions and leopards on foot and assisting police in tracking dangerous criminals.

Initiated Training and Evaluation of trackers in 1994 in South Africa. The CyberTracker Tracker Evaluation system has gained international recognition for maintaining the highest standards for animal tracking. It has also been adopted in the USA for evaluating trackers and biologists working in the wildlife sciences. It is also being introduced to Namibia, Botswana, the UK, Spain and other countries.

Working in collaboration with software programmer Justin Steventon, the development of the CyberTracker software has been ongoing since 1996.

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